AD-A256 255

US Army Corps
of Engineers
Construction Engineering
Research Laboratory

USACERL Technical Report FF-92/08
July 1992

(2)

# Seven-Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units

by
Robert D. Neathammer



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# REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188



1. AGENCY USE ONLY (Leave Blank)

2. REPORT DATE
July 1992

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
Seven-Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units

5. FUNDING NUMBERS
IAOs: FHAA022-83 dated Aug. 83
RO390-84 dated May 1984
SO40-85, dated Jan. 85
TO16-86, dated Nov 86
CERL 87 dated Dec 87
CERL 88 dated Jun 88
CERL 89 dated Mar 89
FAD 90-080031 dated Sep 90
FAD 91-080025 dated Sep 91

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Construction Engineering Research Laboratory (USACERL)
PO Box 9005
Champaign, IL 61826-9005

8. PERFORMING ORGANIZATION REPORT NUMBER
TR FF-92/08

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
USA Engineering and Housing Support Center
ATTN: CEHSC-HM-O
20 Massachusetts Avenue NW
Washington, DC 20001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

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14. SUBJECT TERMS
Fort Irwin, CA
family housing
building components

15. NUMBER OF PAGES
62

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT
SAR

# FOREWORD

This research was conducted for the U.S. Army Engineering and Housing Support Center (USAEHSC), under the following Intra Agency Orders (IAOs) from Fort Irwin and Headquarters, U.S. Army Forces Command (FORSCOM): FHAA022-83, dated August 1983; R039-84, dated May 1984; S040-85, dated January 1985; T016-86, dated November 1986; CERL-87, dated December 1987; CERL-88, dated June 1988; CERL-89, dated 2 March 1989; Headquarters, U.S. Army Corps of Engineers (HQUSACE) FAD 90-080031, dated September 1990; and (HQUSACOE) FAD 91-080025, dated September 1991. The USAEHSC technical monitor was Mr. Alex Houtzager (CEHSC-HM-O). Other technical advisors from USAEHSC were Mr. Robert Lubbert and Mr. Joe Hovell. Coordination and advice from FORSCOM were provided by Mr. Bill Mann, FCEN-RDM. The Fort Irwin advisor was Mr. Tom Cragg.

The work was performed by the Facility Systems Division (FF), of the Infrastructure Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). The principal investigator was Mr. Robert Neathammer, CECER-FFR. Mr. Allen Moore is Chief, CECER-FF. Dr. Michael O'Connor is Chief, CECER-FL. Valuable assistance was provided by Mr. Robert F. Doerr, Jr., CECER-FFR.

COL Daniel Waldo, Jr., is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

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# SEVEN-YEAR SUMMARY OF FORT IRWIN, CA, FAMILY HOUSING COMPARISON TEST: OPERATION AND MAINTENANCE COSTS OF MANUFACTURED vs. CONVENTIONALLY BUILT UNITS

## 1 INTRODUCTION

### Background

Congress believes that use of manufactured (factory built) military housing, rather than conventionally built units, will result in lower overall costs and provide durable housing meeting contemporary housing standards. To verify this belief, Congress directed the Department of Defense (DOD) to construct 200 units of manufactured housing at Fort Irwin, CA, and compare them with similarly designed, conventionally built housing.[1] DOD was also directed to perform a study comparing the operation and maintenance (O&M) costs of the two types of construction over a 5-year period.

Results of the 5-year study showed no difference in O&M costs between the two types of construction. However, the Assistant Secretary of Army for Installations, Logistics, and Environment, the U.S. Army Engineering and Housing Support Center (USAEHSC), and the U.S. Army Construction Engineering Research Laboratory (USACERL) all think 5 years is too short a time for valid comparisons of these types of costs. Thus, USACERL was requested to continue collecting and analyzing data and report results at the end of each year in order to identify broad trends.

The manufactured units met Federal Manufactured Housing Construction and Safety Standards (FMHCSS); however, upgrades in certain criteria were specified to bring the units into conformance with DOD standards. These areas of concern included net usable floor space, energy efficiency, fire and life safety, and durability of certain materials and components. The study compared the impact of the modified FMHCSS versus standard DOD criteria, except for the essential criteria listed above.

The study began when the housing units were first occupied; initial occupancy of some units started in February 1983. The study compares 200 two-bedroom manufactured units to 144 two-bedroom, conventionally built units. The two types of units were similar in floor area, floor plans and materials used. The conditions and parameters for this test were submitted to Congress.

The data collected address O&M costs for both types of housing. The study identifies not only the differences, if any, in O&M costs, but also the reasons for the differences and their importance for future construction criteria, and construction methods.

### Objective

This report summarizes the O&M costs for both conventionally built and manufactured housing from construction through the first 7 years of occupancy.

[1] Report No. 97-44, *Military Construction Authorization Act* (House of Representatives Committee on Armed Services, 1982), pp 8-9.

## Approach

The first step was to develop uniform data collection and data analysis procedures. The cost comparisons and analyses for this study were established in USACERL Special Report (SR) P-140.[2] Data were collected throughout the study and summarized/reported yearly. First year data were reported in USACERL Interim Report (IR) P-85/14,[3] second year data in USACERL IR P-86/06,[4] third year data in USACERL IR P-87/10,[5] fourth year data in USACERL IR P-88/09,[6] 4 1/2 year data in USACERL IP P-89/14,[7] fifth year data in USACERL TR P-90/11,[8] and sixth year data in USACERL TR P-91/37.[9]

Individuals were assigned to quarters with no distinction between the two types of units. The units all have the same floor area and were to be occupied by essentially the same ranks/ages of sponsors; i.e., the assignment of families was not biased by the type of construction.

## Scope

Costs were limited to buildings themselves, as the intent of the study was to compare O&M costs of the two types of construction. Thus, sidewalks, driveways, streets, lawns, playgrounds, and utility lines outside the buildings were not included. Also, the replacement costs of refrigerators, kitchen stoves, and utility meters were excluded. (Because of these exclusions, the unit cost data in this report *is not comparable* to standard unit cost data reported for family housing in many Army financial reports, which normally includes costs such as streets and utilities.)

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[2] M.J. O'Connor, *Fort Irwin Housing Comparison Test*, Special Report (SR) P-140/ADA130349 (USACERL, 1983).

[3] R.D. Neathammer, *Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, Interim Report (IR) P-85/14/ADA159740 (USACERL, 1985).

[4] R.D. Neathammer, *Two Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, IR P-86/06/ADA175995 (USACERL, 1986).

[5] R.D. Neathammer, *Three Year Summary of Fort Irwin, CA, Family Housing Comparison Test; Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, IR P-87/10/ ADA180001 (USACERL, 1987).

[6] R.D. Neathammer, *Four-Year Summary of Fort Irwin, CA, Family Housing Comparison Test; Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, IR P-88/09/ADA190017 (USACERL, 1988).

[7] R.D. Neathammer, *May 1984 to September 1988 Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, IR P-89/14/ADA209421 (USACERL, 1989).

[8] R.D. Neathammer, *Five-Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, TR P-90/11/ADA222176 (USACERL, 1990).

[9] R.D. Neathammer, *Six Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operational Maintenance Costs of Manufactured vs.* Conventionally Built Units, TR P 91/37/ADA237479 (USACERL, 1991).

## 2 REVIEW OF TEST PLAN

This section gives a short review of the test plan and the final data analyses. Data were collected for O&M costs.

USACERL SR P-140 detailed the cost data collection plan and analysis methods. Four basic questions on costs will be answered:

1. Were the average annual O&M costs significantly different?

2. If different, where were they significantly different?

3. Why did the costs differ?

4. What criteria, design features, etc., need to be changed as a result?

Overall maintenance costs and utility costs were compared separately. If significant differences were found, it is important to determine their causes.

In addition to the overall cost comparison, the maintenance costs for major building components were compared. These comparisons provide more detail about where and why cost differences occur.

Occupant satisfaction with the overall apartments and each physical part of the unit was compared for the two types of construction and reported in USACERL P-90/11. When occupant satisfaction differed for a building component, that component was evaluated to determine the reason for the difference.

## 3 DESCRIPTION OF THE FAMILY HOUSING UNITS

### Manufactured Housing Units (MHUs)

These 200 units consist of 50 two-story fourplexes (two units on each of the first and second floors). Net floor area is 950 sq ft/unit.* These were constructed on perimeter footing with wood floors and crawl spaces. Each upper unit has a balcony-porch and each lower one has a patio with privacy fencing. Figure 1 shows front and rear views of typical buildings. Each unit has a refrigerator, gas range, gas water heater, garbage disposal, dishwasher, central air conditioning, and gas-fired forced-air furnace (all provided by the contractor). Each unit has two bedrooms, a kitchen, living-dining area, one bathroom, utility room, and a one-car garage. The garage was constructed on site.

A detailed description of the construction process including photographs and floor plans for the units is shown in Appendix A.

The notice to proceed date was 10 January 1983. Initial occupancy was:

| | | |
|---|---|---|
| 61 | units | Dec 83 |
| 7 | units | Jan 84 |
| 64 | units | Feb 84 |
| 57 | units | Apr 84 |
| 9 | units | May 84 |
| 2 | units | Jun 84 |

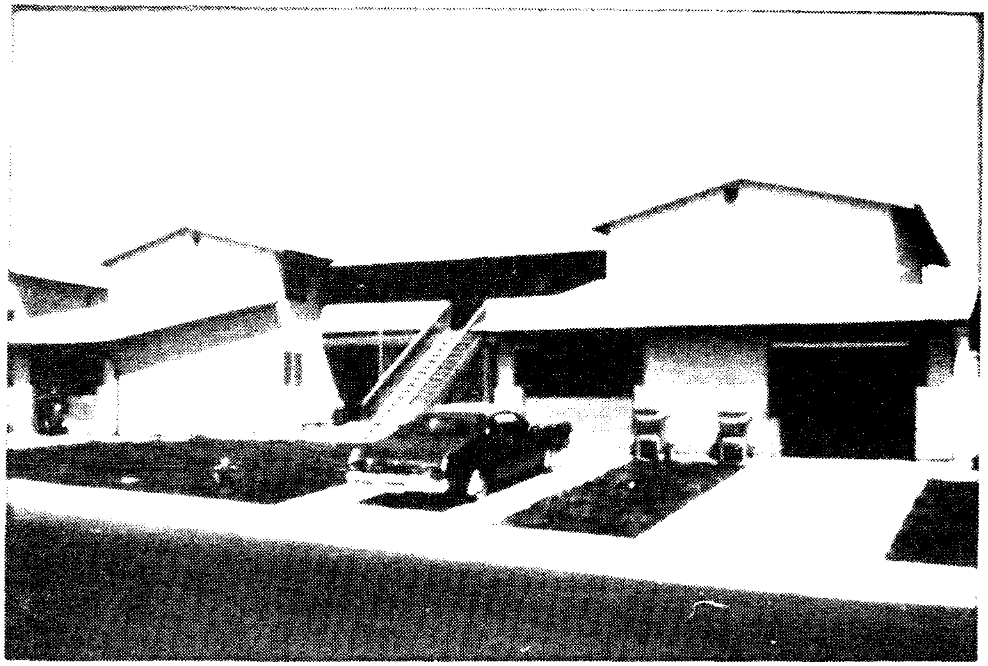
### Conventionally Built Units (CBUs)

The 144 units consist of 13 sixplexes, 6 fiveplexes, and 9 fourplexes, all two-story buildings. Net floor area is 950 sq ft/unit. These units were constructed on perimeter footings with building slab. Each unit has two bedrooms, a kitchen, living-dining area, one bathroom, utility room, either a fenced patio or balcony-porch (for upper unit), and a one-car garage. Figure 2 shows front and rear views of typical buildings. The fourplexes have two units on each level. There are two units on the second story in the five- and sixplexes with the additional unit(s) on the first level. The CBUs also have a refrigerator, gas range, gas water heater, garbage disposal, dishwasher, central air conditioning, and gas-fired forced-air furnace.

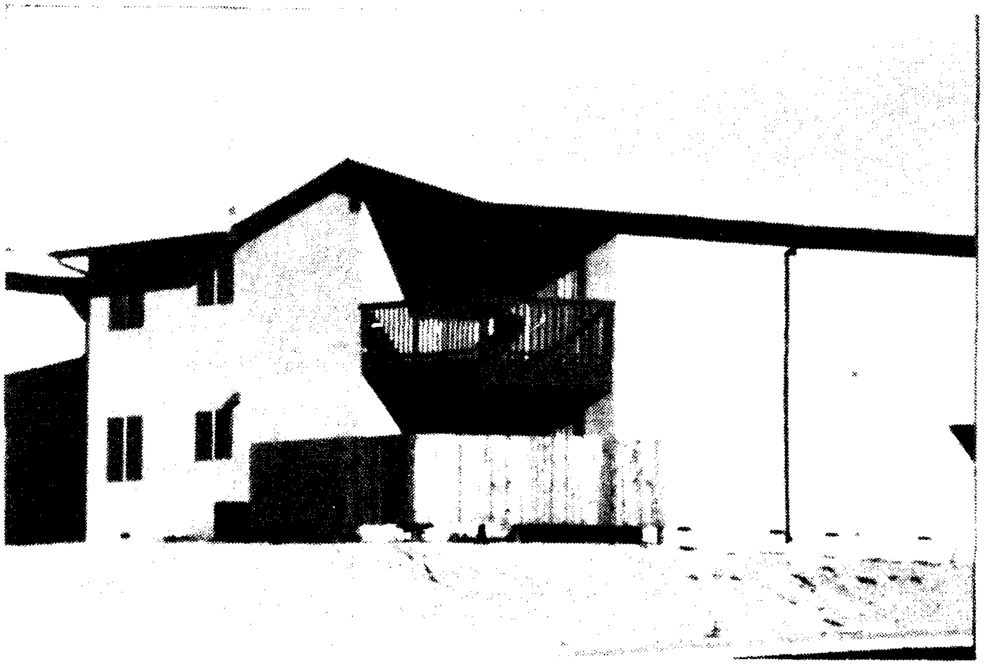
The notice to proceed date was 3 May 1982. Initial occupancy was:

| | | |
|---|---|---|
| 8 | units | Feb 83 |
| 28 | units | Mar 83 |
| 38 | units | Apr 83 |
| 31 | units | May 83 |
| 23 | units | Jun 83 |
| 14 | units | Jul 83 |
| 2 | units | Aug 83 |

*Metric conversions: 1 cu ft = 0.028 $m^3$; 1 sq ft = 0.093 $m^2$; °C = 0.55 x (°F-32).



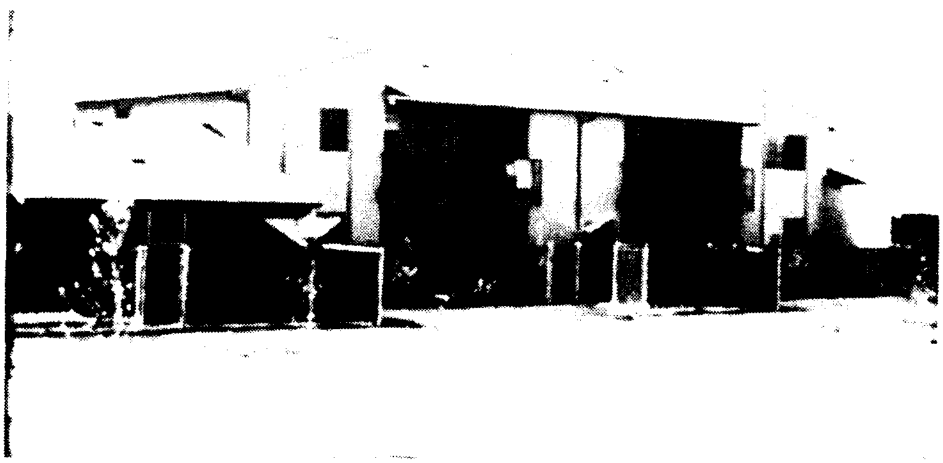
Front View - MHU



Rear View - MHU

**Figure 1. Front and rear views of typical MHUs.**

Front View - CBU



Rear View - CBU

**Figure 2. Front and rear views of typical CBUs.**

A detailed description of all units can be found in the Los Angeles District Office report.[10] The buildings were not specifically adapted to the desert environment but are typical Southern California design.

## Costs

A clear cut initial cost comparison was not possible. The 144 CBUs were part of a 254 unit project. The cost for this project was $51.83/sq ft. The 200 MHUs costs were $51.22/sq ft. However, the supervision and administration costs for the MHUs were based on the same 5 percent rate used for the CBUs. More actual labor was required since quality assurance inspection was required at the manufacturing plant as well as at the construction site. It was estimated that the additional labor would have raised the cost to $55/sq ft (no records were kept as these are all indirect costs).

## General Comparison

Fort Irwin is located in a high desert environment. Annual rainfall averages 4 in. and temperatures often exceed 100 °F. The housing construction was not adapted to this climate but is representative of Southern California design.

The exterior finish of both types is basically stucco. Exterior trim is painted wood. There is some brick veneer on the garages. Asphalt shingles were used on both types, and gutters and downspouts were installed.

On the interiors, walls are painted gypsum board. Floors on the second level are carpeted and are vinyl tile or vinyl sheet covering on the first floor.

Water piping is copper in the CBUs and polybutylene in the MHUs.

Windows are single pane in the MHUs and are thermal pane in the CBUs.

Floors (first story) in MHUs are wood on crawl spaces and in CBUs are concrete slabs.

Grass was planted in the immediate yard area of the buildings, but not in play yard areas. Each first floor unit has a concrete patio, each second story unit a wooden balcony-porch. There is a wooden privacy fencing for each first floor unit.

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[10] *Fort Irwin Family Housing Study--A Report on Manufactured/Factory-Built Housing and Site-Built Housing, Fort Irwin, CA* (U.S. Army Corps of Engineers, Los Angeles District, September 1984).

# 4 DATA COLLECTION PROCEDURES

Data were collected in enough detail that any differences found between the two types of construction could be explained. Appendix B lists the housing units and their identification numbers used in the data collection. Appendix C lists the building components and subcomponents. Each service order was coded to one of these so that costs of components could be compared. A discussion of the data collected is included in USACERL SR P-140.

## Data Collection

Discussions were held with representatives of the USAEHSC technical monitor, Forces Command Headquarters, Fort Irwin personnel, and the base operations contractor, Boeing Services International (BSI), to establish the best methods of collecting the data.

BSI was contracted to segregate all service orders for maintenance for the test units and report cost data to USACERL through the Fort Irwin Directorate of Engineering and Housing (DEH) on a monthly basis. BSI was also contracted to read gas and electric meters at the end of each month and report similarly.

A new contractor, Dynalectron, became the base operations contractor effective 1 October 1986 and performed the same services described above.

## Data Verification

USACERL verified the reported data several ways. For the first 5 years, each original work order (WO) document was checked against the reported data forwarded by the contractor. Discrepancies were resolved on verification visits to Fort Irwin. Additionally, the contractor set up separate accounting codes for the two groups of units and the total billed was compared to the total obtained from summing all the individual WO data. For years 6 and 7, the reported data was checked for obvious errors and these were resolved with the contractor. No detailed validation of each WO was made as the purpose of the continued study is to search for overall, large trends.

USACERL developed a computer program to compare gas and electricity meter readings. When apparently erroneous data occurred, the contractor was notified and corrections made.

## Data Analysis

### *Maintenance Costs*

Maintenance costs were compared on a unit-month basis and yearly basis. The data were also summarized by building component to determine if one or more components for one of the types of units had large maintenance costs. If so, the reasons for these costs were determined; i.e., what criteria or design features should be reviewed/changed?

Cost differences could have been caused by material quality, installation, differences inherent to manufactured or conventional construction, and possible errors in specifications for the two projects.

Warranty work referred to the construction contractor was not included in the cost comparison since no cost data were available or applicable, as it was not a cost to the government. However, the cost of a service call to assess a problem was included.

*Energy Consumption*

Gas and electricity consumption were compared on a quarterly basis and a yearly basis. Since most of the MHUs were not completed until May 1984, prior energy consumption data for the CBUs was not used in comparisons. (Energy consumption comparisons are only valid for the same time frame because of varying weather conditions.)

## 5 WHOLE HOUSE ENERGY TESTS

Energy evaluations of sample units of each type of construction were performed immediately after construction was completed on each of the two groups of housing and again after 5 years of occupancy. The objective was to determine if energy characteristics had changed over the 5-year period. Three whole-house energy tests were performed. Appendices D and E give details of the tests for the CBUs and MHUs, respectively.

### House Tightness

The number of air changes per hour were measured with the following results:

| | Immediately After Construction | | | After 5 Years | | |
|---|---|---|---|---|---|---|
| Type | No. Units | Average Air Change Per Hour | Standard Deviation (%) | No. Units | Average Air Change Per Hour | Standard Deviation (%) |
| CBU | 15 | 13.0 | 1.06 | 15 | 12.1 | 1.70 |
| MHU | 12 | 10.9 | 2.67 | 14 | 9.7 | 1.60 |

There was a statistically significant difference between the two types of construction for both the initial and 5-year tests, the MHUs being more airtight on the average. Neither type of unit changed significantly over the 5 years. These results indicate that the MHUs should have had less air infiltration/leakage.

### Furnace Efficiency

The furnace efficiency results were as follows:

| | Immediately After Construction | | | After 5 Years | | |
|---|---|---|---|---|---|---|
| Type (%) | No. Units | Average Efficiency (%) | Standard Deviation (%) | No. Units | Average Efficiency (%) | Standard Deviation |
| CBU | 13 | 66.2 | 6.24 | 14 | 64.2 | 12.2 |
| MHU | 16 | 79.3 | 3.36 | 15 | 77.3 | 2.84 |

The furnace efficiencies of the MHUs were significantly higher than those of the CBU for both the initial and 5-year tests. Neither type of unit changed significantly over the 5 years.

### Wall Heat Transfer Characteristics

This parameter was not initially measured for the CBUs because of unfavorable weather during the testing period. This parameter was calculated for both types of construction using the designed wall construction.

| Type | No. Units | Average Heat Loss (Btu/hr-$^{o}$F) |
|---|---|---|
| CBU | 16 | 1072 |
| MHU | 15 | 1220 |

## Summary

The whole house energy tests did not conclusively indicate which type of unit would use less energy for heating/cooling. The CBUs are more energy efficient considering only the wall heat loss test, but the MHUs perform better when tested for air tightness and furnace efficiency. Additionally, the CBUs are built on concrete slabs while the MHUs have a crawl space. Concrete slabs are better (use less energy) than crawl spaces. This has an impact on the first floor units' energy use.

Thus the tests are inconclusive in predicting which type of construction would use more energy for heating/cooling.

## 6 OPERATION AND MAINTENANCE (O&M) COSTS

O&M costs for each type of unit were compared over the first 7 years of occupancy. For CBUs, this was 1 August 1983 through 31 July 1990 and for MHUs, 1 June 1984 through 31 May 1991.

### Overall Costs

The total housing unit-months and maintenance costs for the first 7 years of occupancy are shown in Table 1. (Maintenance includes all types of repairs and "preventive maintenance" performed.)

### Discussion

The MHUs cost about $14/month more than the CBUs over the first 7 years of occupancy; the difference in cost per unit per year of an MHU is $164. There were large increases in M&R costs in years 4 and 5. This is illustrated in Table 2, which shows M&R costs per year of occupancy.

**Table 1**

**Unit/Month Costs in First 7 Years' Occupancy**

| Type | No. Unit Months | Total Cost ($) | Cost/Unit/ Month ($) | Cost/Unit/ Year ($) |
|---|---|---|---|---|
| CBU | 12,096 | 448,326 | 37.06 | 445 |
| MHU | 16,800 | 853,168 | 50.78 | 609 |

**Table 2**

**Yearly M&R Costs by Type of Construction**

| Year | Total CBU ($) | Cost/Unit ($) | Total MHU ($) | Cost/Unit ($) |
|---|---|---|---|---|
| 1 | 31,592 | 219 | 34,164 | 171 |
| 2 | 29,107 | 202 | 59,076 | 295 |
| 3 | 44,391 | 308 | 63,717 | 319 |
| 4 | 45,565 | 316 | 114,728 | 574 |
| 5 | 89,186 | 619 | 189,122 | 946 |
| 6 | 96,700 | 672 | 175,725 | 879 |
| 7 | 111,785 | 776 | 216,636 | 1083 |
| 7 Year Total | 448,326 | 445 | 853,168 | 609 |

Costs per unit have been increasing over time. Figure 3 shows the cumulative cost per unit per month for ages 15 to 84 months, illustrating this trend. The costs for the MHUs increased slightly faster than for the CBUs. This can also be seen in Figure 4, which shows costs per unit per year.

Increased costs in years 4 and 5 were attributable partly to interior painting done in units vacated for the first time and in those which required painting on change of occupancy. Table 3 shows the painting costs per year of occupancy. Note the large increases for MHUs in year 5 and for CBUs in year 6. Painting costs for the MHUs may have stabilized in years 6 and 7.

Table 4 shows the yearly costs excluding interior painting. This table shows that the MHUs' costs increased slightly faster than did the CBUs' through year 5. Both showed decreases in year 6 and increases in year 7. Figure 5 displays this data.

### Costs Excluding Certain Equipment Costs

Since the purpose of this study was to compare maintenance costs attributable to method of construction, another table was generated excluding certain costs. Table 5 gives the costs for the 7 years of occupancy of each type unit, excluding any costs for maintenance of water heaters, garbage disposals, dishwashers, ranges, range hoods, and refrigerators (equipment not part of the construction process).

The difference in cost per unit per year between types of construction is \$122/year. Compared to the \$164 in Table 1, this is a better estimate of the cost difference attributable to the type of construction.

### Costs Excluding Interior Painting and Equipment Costs

In Table 6 equipment costs and painting costs are excluded. The difference for unit cost is \$85 per year. Figure 6 graphs the data of Table 6.

### Number of Component Action and Work Orders

Table 7 lists the number of component actions and work orders per year.

### Maintenance Per Component

Table 8 lists the frequencies of work orders and costs per building component for the two types of units. However, the costs were not directly comparable across the two types of units since there were 200 MHUs and 144 CBUs. Table 9 shows the cost data adjusted by multiplying the MHU costs by 0.72 (144/200). Also shown in Table 9 are the 7-year costs on a unit basis.

Table 9 shows that the total cost was less than \$500 for both types for 21 of the 78 components. For 42 of the other 57 components, the MHUs had a higher cost.

Most of the costs shown in Tables 8 and 9 were for building components independent of type of construction. For example, over \$15K was spent on the ranges for each type unit, \$16K for CBUs and \$60K for MHUs was spent on dishwashers, over \$20K on light fixtures for each type, etc. The most significant costs for components which differ for the types were roofing surface, exterior doors, garage doors, A/C refrigerant, bathroom/kitchen fixtures, and piping. Although a large difference existed for painting, this cost depended on rotation of occupants and occupant wear and tear. Complete quarters painting was done on 223 MHUs and only 114 CBUs.

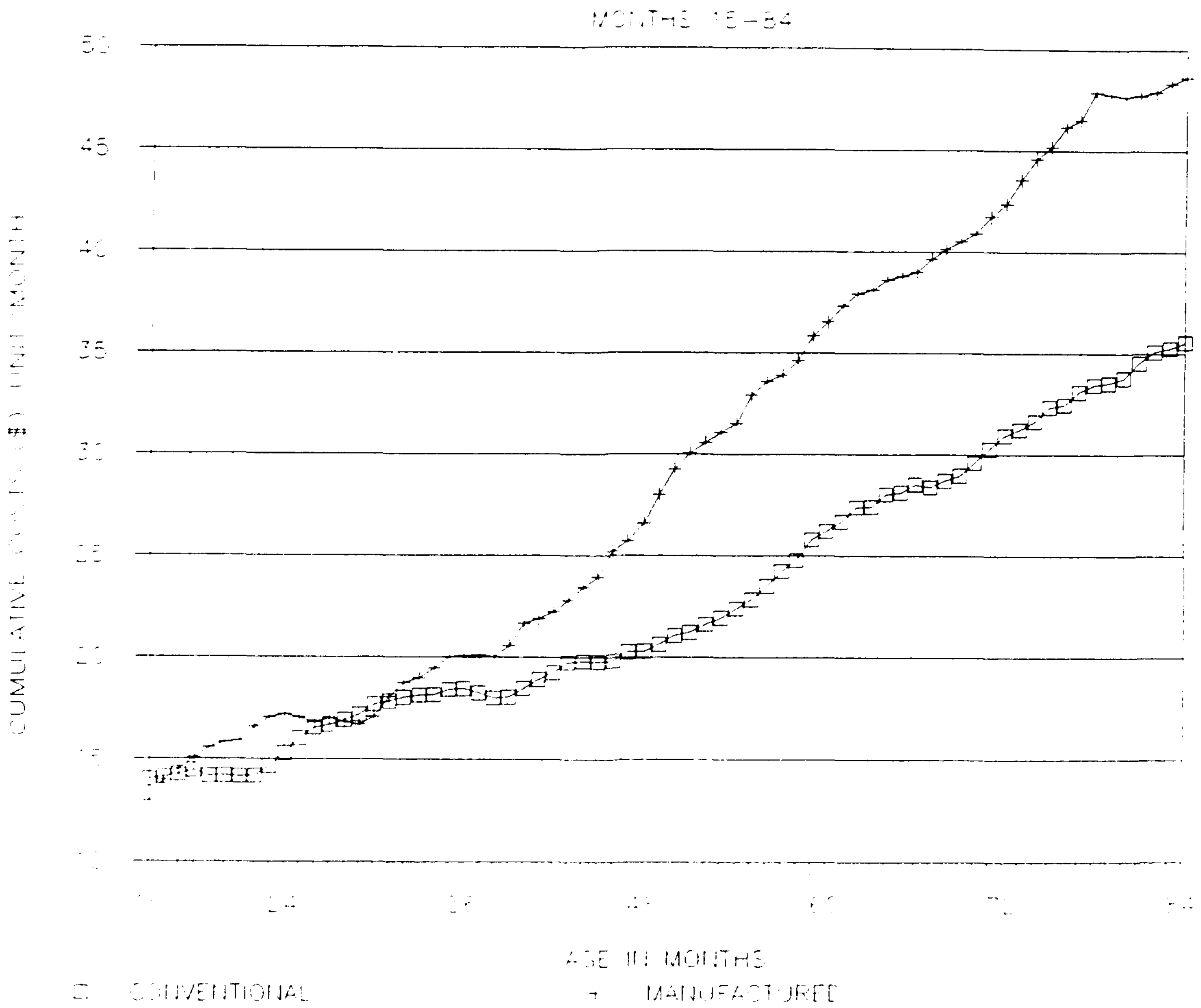


**Figure 3. Cumulative cost per unit per month for ages 15 through 84 months.**

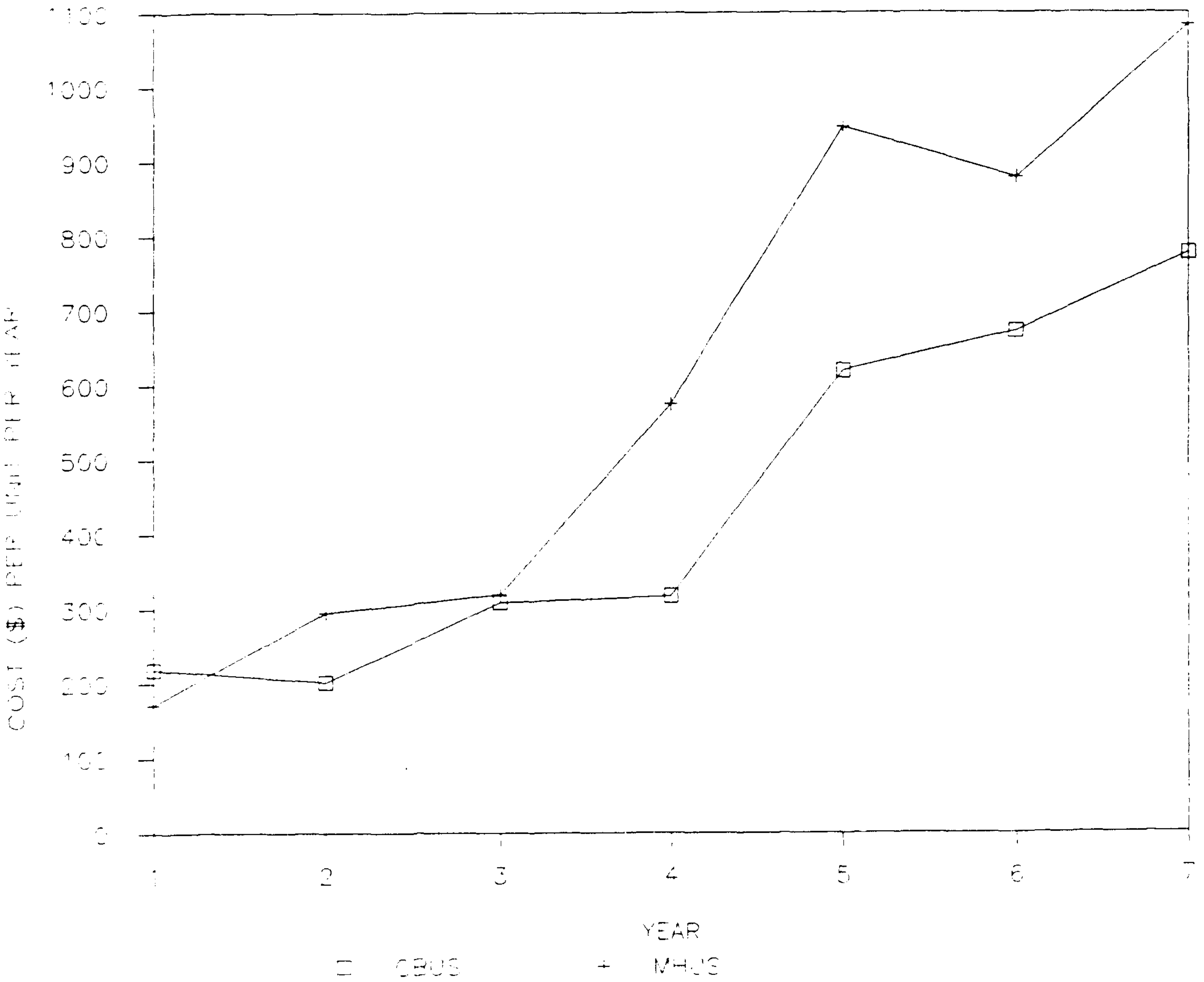


Figure 4. Total costs per unit per year.

Table 3

**Interior Painting Costs**

| Year | Total CBU (S) | Cost/Unit (S) | Total MHU (S) | Cost/Unit (S) |
|---|---|---|---|---|
| 1 | 603 | 4 | 317 | 2 |
| 2 | 1,288 | 9 | 4,684 | 23 |
| 3 | 7,312 | 51 | 13,741 | 69 |
| 4 | 11,537 | 80 | 24,386 | 122 |
| 5 | 29,779 | 207 | 80,499 | 402 |
| 6 | 49,481 | 344 | 74,916 | 375 |
| 7 | 53,428 | 371 | 66,959 | 335 |
| 7-Year Total | 153,428 | 152 | 265,502 | 190 |

Table 4

**Yearly M&R Costs Excluding Interior Painting Costs**

| Year | Total CBU (S) | Cost/Unit (S) | Total MHU (S) | Cost/Unit (S) |
|---|---|---|---|---|
| 1 | 30,989 | 215 | 33,905 | 170 |
| 2 | 27,819 | 193 | 54,392 | 272 |
| 3 | 37,079 | 257 | 49,976 | 250 |
| 4 | 34,028 | 236 | 90,342 | 452 |
| 5 | 59,407 | 413 | 108,623 | 543 |
| 6 | 47,219 | 328 | 100,809 | 504 |
| 7 | 58,357 | 405 | 149,677 | 748 |

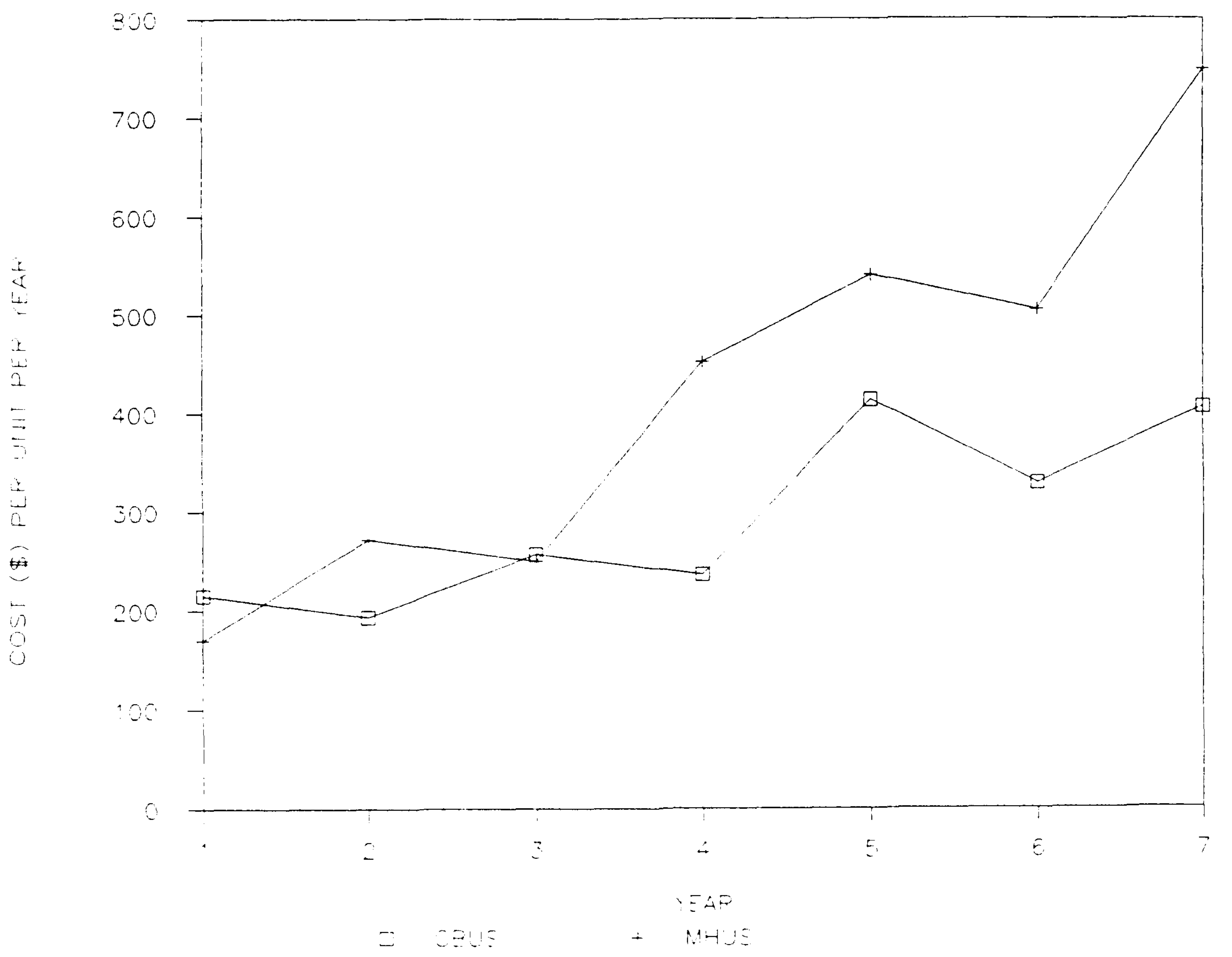


Figure 5. Costs per unit per year excluding interior painting costs.

**Table 5**

**Unit Costs Excluding Certain Equipment Costs**

| Year | Total CBU ($) | Cost/ Unit ($) | Total MHU ($) | Cost/ Unit ($) |
|---|---|---|---|---|
| 1 | 25,570 | 178 | 26,279 | 131 |
| 2 | 25,128 | 174 | 48,416 | 242 |
| 3 | 37,275 | 259 | 53,789 | 269 |
| 4 | 40,465 | 281 | 96,381 | 482 |
| 5 | 80,998 | 562 | 164,253 | 821 |
| 6 | 90,662 | 630 | 146,019 | 730 |
| 7 | 102,665 | 713 | 195,090 | 975 |
| 7-Year Total | 402,754 | 400 | 730,227 | 522 |

**Table 6**

**Unit Costs Excluding Certain Equipment and Painting Costs**

| | Total Costs ($) | | Cost/Unit ($) | |
|---|---|---|---|---|
| Year | CBU | MHU | CBU | MHU |
| 1 | 24,967 | 25,962 | 173 | 130 |
| 2 | 23,840 | 43,732 | 166 | 219 |
| 3 | 29,963 | 40,048 | 208 | 200 |
| 4 | 28,928 | 71,995 | 201 | 360 |
| 5 | 51,219 | 83,754 | 356 | 419 |
| 6 | 41,181 | 71,103 | 286 | 356 |
| 7 | 49,227 | 128,131 | 342 | 629 |
| 7-Year Total | 249,326 | 464,726 | 247 | 332 |

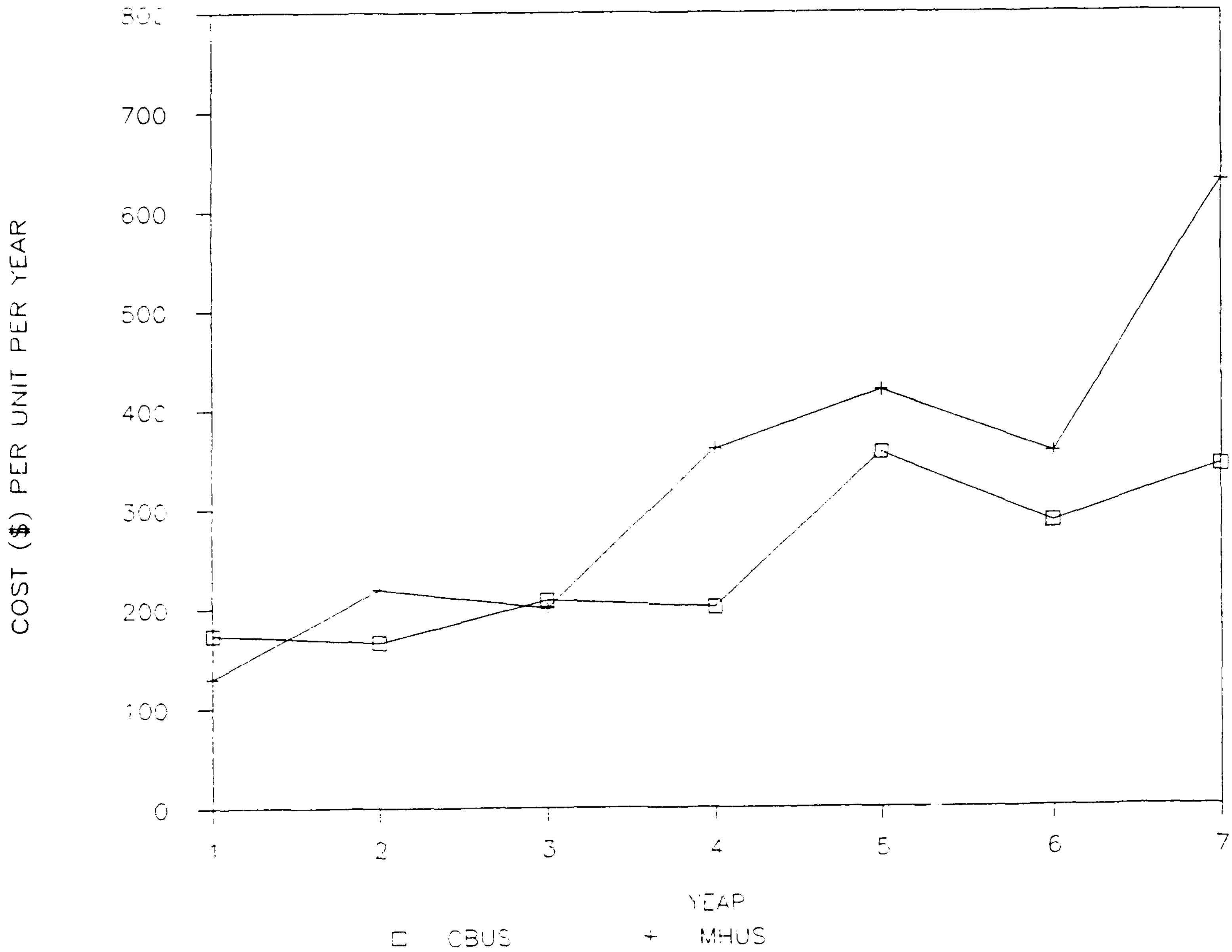


Figure 6. Costs per unit per year excluding certain equipment and painting costs.

Table 7

Component Actions and Work Orders*

| | MHU | | | CBU | | |
|---|---|---|---|---|---|---|
| Year | Number Component Actions | Number WOs | Average Number WOs/Unit | Number Component Actions | Number WOs | Average Number WOs/Unit |
| 1 | 1,718 | 1,610 | 8 | 1,139 | 1,128 | 8 |
| 2 | 1,938 | 1,371 | 7 | 989 | 863 | 6 |
| 3 | 2,183 | 1,273 | 6 | 1,404 | 877 | 6 |
| 4 | 4,048 | 1,867 | 9 | 1,592 | 869 | 6 |
| 5 | 3,735 | 2,028 | 10 | 2,920 | 1,335 | 9 |
| 6 | 3,830 | 2,116 | 11 | 2,506 | 1,247 | 9 |
| 7 | 3,622 | 2,004 | 10 | 2,452 | 1,288 | 9 |
| Total | 21,093 | 12,269 | 61 | 13,052 | 7,607 | 53 |

*One work order (WO) may have several component repairs.

Note the $17,767 cost for exterior-trim painting of MHUs and $0 for CBUs. The exterior trim was to be painted on a cyclic basis. The CBU cycle in 1988 was deferred. Both CBU and MHU exterior-trim painting for 1989/90 was deferred.

Table 10 summarizes Table 9 data into the 12 major building component codes (Appendix C). Although the 0201-0220 structure is a high cost item, Table 9 shows most of these costs are related to doors and windows, and much of the damage to these items was occupant caused.

## Water Piping Problems

The manufacturer used polybutylene piping in the CBU units. The piping was installed in the building modules at the plant in Southern California and many connections made after the modules were assembled together at Fort Irwin (after 200 miles of transportation).

These manufactured apartments are two story fourplexes, two units above two units. Piping runs through walls, the ceiling of the first floor units (i.e., the floor of the second floor units) and under the first floor units in the crawl space.

There have been many leaks in the piping. There have been two major breaks in a "tee" joint in the ceiling of the first floor units of the MHUs. A detailed analysis of plumbing service orders shows a higher cost for MHUs for the category leaking or broken piping. Costs for each of the 7 years are shown in Table 11.

Table 8

Maintenance Actions Performed and Costs Per Component

| Component | | Maintenance/Repair Actions | | | | Cost ($) | | | |
|---|---|---|---|---|---|---|---|---|---|
| No. | Description | CBU (N=13,052)* | | MHU (N=21,093) | | CBU (Total= 448,326) | | MHU (Total= 853,168) | |
| 101 | Roofing surface | 114 | (1%)** | 336 | (2%) | 9082 | (2%) | 30803 | (4%) |
| 103 | Flashing, vents | 22 | | 13 | | 488 | | 490 | |
| 104 | Gutters and downspouts | 238 | (2%) | 314 | (1%) | 3591 | (1%) | 4707 | (1%) |
| 105 | Other roof repairs | 0 | | 2 | | 0 | | 16 | |
| 201 | Foundation and anchorage | 3 | | 2 | | 24 | | 24 | |
| 202 | Structure | 17 | | 61 | | 251 | | 2039 | |
| 203 | Insulation | 3 | | 0 | | 42 | | 0 | |
| 204 | Masonry | 10 | | 10 | | 240 | | 260 | |
| 205 | Exterior siding | 4 | | 2 | | 207 | | 238 | |
| 206 | Exterior doors and frames | 453 | (3%) | 811 | (4%) | 9331 | (2%) | 18260 | (2%) |
| 207 | Storm and screen doors | 608 | (5%) | 930 | (4%) | 18408 | (4%) | 33147 | (4%) |
| 208 | Windows and frames | 143 | (1%) | 206 | (1%) | 3053 | (1%) | 4541 | (1%) |
| 209 | Storm windows and screens | 302 | (2%) | 309 | (1%) | 6129 | (1%) | 5744 | (1%) |
| 210 | Exterior trim | 0 | | 2 | | 0 | | 26 | |
| 211 | Porch/deck | 5 | | 3 | | 102 | | 106 | |
| 212 | Interior drywall | 197 | (2%) | 401 | (2%) | 4746 | (1%) | 17616 | (2%) |
| 213 | Wall coverings and paneling | 12 | | 0 | | 200 | | 0 | |
| 214 | Interior doors | 1194 | (9%) | 1354 | (6%) | 20633 | (5%) | 20428 | (2%) |
| 215 | Interior casework | 43 | | 70 | | 567 | | 1125 | |
| 216 | Bathroom accessories | 170 | (1%) | 235 | (1%) | 2931 | (1%) | 2814 | |
| 217 | Kitchen accessories, cabinets | 308 | (2%) | 474 | (2%) | 4111 | (1%) | 7419 | (1%) |
| 218 | Drapery hardware | 17 | | 89 | | 268 | | 1614 | |
| 219 | Other exterior/interior | 193 | (1%) | 293 | (1%) | 4968 | (1%) | 13692 | (2%) |
| 220 | Garage doors | 589 | (5%) | 455 | (2%) | 12284 | (3%) | 7917 | (1%) |
| 301 | Resilient flooring | 47 | | 293 | (1%) | 1590 | | 9788 | (1%) |
| 302 | Carpet and pad | 8 | | 40 | | 105 | | 2720 | |
| 304 | Underlayment/substrate | 2 | | 6 | | 13 | | 70 | |
| 305 | Other flooring | 25 | | 98 | | 940 | | 15662 | (2%) |
| 401 | Paint, walls and ceilings | 243 | (2%) | 350 | (2%) | 150912 | (34%) | 259321 | (30%) |
| 402 | Paint, trim | 1 | | 0 | | 20 | | 0 | |
| 403 | Paint, touchup, interior | 63 | | 171 | (1%) | 1703 | | 5262 | (1%) |
| 404 | Bathtub, shower caulking | 203 | (2%) | 347 | (2%) | 2241 | | 4413 | (1%) |
| 405 | Other interior painting | 34 | | 20 | | 792 | | 918 | |
| 501 | Paint, exterior walls | 3 | | 3 | | 92 | | 45 | |
| 502 | Paint, exterior doors, frames | 5 | | 4 | | 138 | | 79 | |
| 503 | Paint, exterior trim | 0 | | 13 | | 0 | | 17767 | (2%) |
| 504 | Exterior caulking | 0 | | 1 | | 0 | | 20 | |
| 506 | Other exterior painting | 2 | | 3 | | 44 | | 75 | |

*N = Number of maintenance actions

**Percents are given for number maintenance actions and costs when the value is 1% or more of the total.

Table 8 (Cont'd)

| Component | | Maintenance/Repair Actions | | | | Cost ($) | | | |
|---|---|---|---|---|---|---|---|---|---|
| No. | Description | CBU | | MHU | | CBU | | MHU | |
| 601 | Heating plant, valve | 102 | (1%) | 55 | | 3617 | (1%) | 2855 | |
| 602 | Motors, blowers, pumps | 60 | | 83 | | 4277 | (1%) | 5529 | (1%) |
| 603 | Ducts | 1 | | 25 | | 15 | | 1225 | |
| 604 | Piping | 7 | | 2 | | 190 | | 23 | |
| 605 | Diffusers, grills | 13 | | 65 | | 202 | | 920 | |
| 606 | Insulation | 0 | | 2 | | 0 | | 61 | |
| 607 | Heating controls | 139 | (1%) | 99 | | 6073 | (1%) | 4374 | (1%) |
| 608 | Other heating | 475 | (4%) | 733 | (3%) | 6630 | (1%) | 11166 | (1%) |
| 701 | Cooling coils, compressor | 43 | | 44 | | 8065 | (2%) | 2386 | |
| 702 | A/C motors, blowers, pumps | 96 | (1%) | 117 | (1%) | 7172 | (2%) | 5928 | (1%) |
| 703 | A/C piping, ducting | 6 | | 38 | | 160 | | 1157 | |
| 704 | A/C refrigerant | 391 | (3%) | 204 | (1%) | 13761 | (3%) | 6996 | (1%) |
| 705 | A/C insulation | 1 | | 0 | | 7 | | 0 | |
| 706 | A/C controls | 99 | (1%) | 82 | | 4242 | (1%) | 3126 | |
| 707 | Other cooling | 573 | (4%) | 815 | (4%) | 12671 | (3%) | 16796 | (2%) |
| 801 | Water heater | 254 | (2%) | 473 | (2%) | 5626 | (1%) | 14542 | (2%) |
| 803 | Piping, supply | 107 | (1%) | 575 | (3%) | 3216 | (1%) | 25554 | (3%) |
| 804 | Faucets and shower heads | 562 | (4%) | 1409 | (7%) | 12476 | (3%) | 32180 | (4%) |
| 805 | Lavatories | 308 | (2%) | 839 | (4%) | 4729 | (1%) | 21439 | (3%) |
| 806 | Water closets | 655 | (5%) | 1039 | (5%) | 11732 | (3%) | 19249 | (2%) |
| 807 | Bathtub/shower unit | 97 | (1%) | 371 | (2%) | 1555 | | 7830 | (1%) |
| 809 | Other plumbing | 182 | (1%) | 426 | (2%) | 3672 | (1%) | 10635 | (1%) |
| 901 | Service entrance | 2 | | 2 | | 65 | | 188 | |
| 902 | Panel box/circuit breakers | 62 | | 155 | (1%) | 1949 | | 5811 | (1%) |
| 903 | Branch circuits | 19 | | 21 | | 532 | | 1358 | |
| 904 | Wall receptacles | 282 | (2%) | 485 | (2%) | 4342 | (1%) | 8810 | (1%) |
| 905 | Doorbells and chimes | 1 | | 1 | | 15 | | 4 | |
| 906 | Light fixtures | 1211 | (9%) | 1189 | (6%) | 20270 | (5%) | 22140 | (3%) |
| 907 | Vents, fans | 35 | | 47 | | 656 | | 926 | |
| 908 | Other electrical | 38 | | 42 | | 872 | | 2901 | |
| 1001 | Garbage disposal | 318 | (2%) | 648 | (3%) | 6011 | (1%) | 14086 | (2%) |
| 1002 | Dishwasher | 298 | (2%) | 888 | (4%) | 16133 | (4%) | 60845 | (7%) |
| 1003 | Range | 697 | (5%) | 1125 | (5%) | 15149 | (3%) | 21166 | (2%) |
| 1004 | Range hood | 64 | | 65 | | 955 | | 824 | |
| 1005 | Refrigerator | 97 | (1%) | 384 | (2%) | 1717 | | 11478 | (1%) |
| 1006 | Other equipment | 146 | (1%) | 222 | (1%) | 1450 | | 2341 | |
| 1201 | Water supply | 75 | (1%) | 133 | (1%) | | 1928 | | 3964 |
| 1202 | Gas supply | 78 | (1%) | 120 | (1%) | 2318 | (1%) | 3235 | |
| 1203 | Electrical service | 50 | | 75 | | 1636 | | 6757 | (1%) |
| 1204 | Sanitary/sewer lines | 5 | | 4 | | 657 | | 191 | |
| 1205 | Other utility service | 0 | | 1 | | 0 | | 8 | |
| 1300 | Miscellaneous | 122 | (1%) | 270 | (1%) | 1316 | | 3000 | |

Table 9

Maintenance Costs Per Component, Adjusted by Number of Units

| Component | | Costs ($) | | | | |
|---|---|---|---|---|---|---|
| No. | Description | CBU | MHU | MHU Adjusted* | CBU/144** | MHU/200** |
| 101 | Roofing surface | 9082 | 30803 | 22178 | 63.07 | 154.02 |
| 103 | Flashing, vents | 488 | 490 | 353 | 3.39 | 2.45 |
| 104 | Gutters and downspouts | 3591 | 4707 | 3389 | 24.94 | 23.54 |
| 105 | Other roof repairs | 0 | 16 | 12 | 0.00 | 0.08 |
| 201 | Foundations and anchorage | 24 | 24 | 17 | 0.17 | 0.12 |
| 202 | Structure | 251 | 2039 | 1468 | 1.74 | 10.20 |
| 203 | Insulation | 42 | 0 | 0 | 0.29 | 0.00 |
| 204 | Masonry | 240 | 260 | 187 | 1.67 | 1.30 |
| 205 | Exterior siding | 207 | 238 | 171 | 1.44 | 1.19 |
| 206 | Exterior doors and frames | 9331 | 18260 | 13147 | 64.80 | 91.30 |
| 207 | Storm and screen doors | 18408 | 33147 | 23866 | 127.83 | 165.74 |
| 208 | Windows and frames | 3053 | 4541 | 3270 | 21.20 | 22.71 |
| 209 | Storm windows and screens | 6129 | 5744 | 4136 | 42.56 | 28.72 |
| 210 | Exterior trim | 0 | 26 | 19 | 0.00 | 0.13 |
| 211 | Porch/deck | 102 | 106 | 76 | 0.71 | 0.53 |
| 212 | Interior drywall | 4746 | 17616 | 6426 | 32.96 | 88.08 |
| 213 | Wall coverings and paneling | 200 | 0 | 0 | 1.39 | 0.00 |
| 214 | Interior doors | 20633 | 20428 | 12684 | 143.28 | 102.14 |
| 215 | Interior casework | 567 | 1125 | 810 | 3.94 | 5.63 |
| 216 | Bathroom accessories | 2931 | 2814 | 2026 | 20.35 | 14.07 |
| 217 | Kitchen accessories, cabinets | 4111 | 7419 | 5342 | 28.55 | 37.10 |
| 218 | Drapery hardware | 268 | 1614 | 1162 | 1.86 | 8.07 |
| 219 | Other exterior/interior | 4968 | 13692 | 9858 | 34.50 | 68.46 |
| 220 | Garage doors | 12284 | 7917 | 5700 | 85.31 | 39.59 |
| 301 | Resilient flooring | 1590 | 9788 | 7047 | 11.04 | 48.94 |
| 302 | Carpet and pad | 105 | 2720 | 1958 | 0.73 | 13.60 |
| 304 | Underlayment/substrate | 13 | 70 | 50 | 0.09 | 0.35 |
| 305 | Other flooring | 940 | 15662 | 11277 | 6.53 | 78.31 |
| 401 | Paint, walls and ceilings | 150912 | 259321 | 186711 | 1048.00 | 1296.61 |
| 402 | Paint, trim | 20 | 0 | 0 | 0.14 | 0.00 |
| 403 | Paint, touchup, interior | 1703 | 5262 | 3789 | 11.83 | 26.31 |
| 404 | Bathtub, shower caulking | 2241 | 4413 | 3177 | 15.56 | 22.07 |
| 405 | Other interior painting | 792 | 918 | 661 | 5.50 | 4.59 |
| 501 | Paint, exterior walls | 92 | 45 | 32 | 0.64 | 0.23 |
| 502 | Paint, exterior doors, frames | 138 | 79 | 57 | 0.96 | 0.40 |
| 503 | Paint, exterior trim | 0 | 17767 | 12791 | 0.00 | 88.84 |
| 504 | Exterior caulking | 0 | 20 | 14 | 0.00 | 0.10 |
| 506 | Other exterior painting | 44 | 75 | 54 | 0.31 | 0.38 |
| 601 | Heating plant, valve | 3617 | 2855 | 2056 | 25.12 | 14.28 |
| 602 | Motors, blowers, pumps | 4277 | 5529 | 3981 | 29.70 | 27.65 |

*The MHU column adjusted by multiplying by 0.72.

**These are costs per unit for the 7 years.

Table 9 (Cont'd)

| Component | | | Costs ($) | | | |
|---|---|---|---|---|---|---|
| No. | Description | CBU | MHU | MHU Adjusted | CBU/144 | MHU/200 |
| 603 | Ducts | 15 | 1225 | 882 | 0.10 | 6.13 |
| 604 | Piping | 190 | 23 | 17 | 1.32 | 0.12 |
| 605 | Diffusers, grills | 202 | 920 | 662 | 1.40 | 4.60 |
| 606 | Insulation | 0 | 61 | 44 | 0 | 0.31 |
| 607 | Heating controls | 6073 | 4374 | 3149 | 42.17 | 21.87 |
| 608 | Other heating | 6630 | 11166 | 8040 | 46.04 | 55.83 |
| 701 | Cooling coils, compressor | 8065 | 2386 | 1718 | 56.01 | 11.93 |
| 702 | A/C motors, blowers, pumps | 7172 | 5928 | 4268 | 49.81 | 29.64 |
| 703 | A/C piping, ducts | 160 | 1157 | 833 | 1.11 | 5.79 |
| 704 | A/C refrigerant | 13761 | 6996 | 5037 | 95.56 | 34.98 |
| 705 | A/C insulation | 7 | 0 | 0 | 0.05 | 0.00 |
| 706 | A/C controls | 4242 | 3126 | 2251 | 29.46 | 15.63 |
| 707 | Other cooling | 12671 | 16796 | 12093 | 87.99 | 83.98 |
| 801 | Water heater | 5626 | 14542 | 10470 | 39.07 | 72.71 |
| 803 | Piping, supply | 3216 | 25554 | 18399 | 22.33 | 127.77 |
| 804 | Faucets and shower heads | 12476 | 32180 | 23170 | 86.64 | 160.90 |
| 805 | Lavatories | 4729 | 21439 | 15436 | 32.84 | 107.20 |
| 806 | Water closets | 11732 | 19249 | 13859 | 81.47 | 96.25 |
| 807 | Bathtub/shower unit | 1555 | 7830 | 5638 | 10.80 | 39.15 |
| 809 | Other plumbing | 3672 | 10635 | 7657 | 25.50 | 53.18 |
| 901 | Service entrance | 65 | 188 | 135 | 0.45 | 0.94 |
| 902 | Panel box/circuit breakers | 1949 | 5811 | 4184 | 13.53 | 29.06 |
| 903 | Branch circuits | 532 | 1358 | 978 | 3.69 | 6.79 |
| 904 | Wall receptacles | 4342 | 8810 | 6343 | 30.15 | 44.05 |
| 905 | Doorbells and chimes | 15 | 4 | 3 | 0.10 | 0.02 |
| 906 | Light fixtures | 20270 | 22140 | 15941 | 140.76 | 110.70 |
| 907 | Vents, fans | 656 | 926 | 667 | 4.56 | 4.63 |
| 908 | Other electrical | 872 | 2901 | 2089 | 6.06 | 14.51 |
| 1001 | Garbage disposal | 6011 | 14086 | 10142 | 41.74 | 70.43 |
| 1002 | Dishwasher | 16133 | 60845 | 43808 | 112.03 | 304.23 |
| 1003 | Range | 15149 | 21166 | 15240 | 105.20 | 105.83 |
| 1004 | Range hood | 955 | 824 | 593 | 6.63 | 4.12 |
| 1005 | Refrigerator | 1717 | 11478 | 8264 | 11.92 | 57.39 |
| 1006 | Other equipment | 1450 | 2341 | 1686 | 10.07 | 11.71 |
| 1201 | Water supply | 1928 | 3964 | 2854 | 13.39 | 19.82 |
| 1202 | Gas supply | 2318 | 3235 | 2329 | 16.10 | 16.18 |
| 1203 | Electrical service | 1636 | 6757 | 4865 | 11.36 | 33.79 |
| 1204 | Sanitary/sewer lines | 657 | 191 | 138 | 4.56 | 0.96 |
| 1205 | Other utility service | 0 | 8 | 6 | 0.00 | 0.04 |
| 1300 | Miscellaneous | 1316 | 3000 | 2160 | 9.14 | 15.00 |
| | Totals | 448,326 | 853,168 | 614,281 | | |

**Table 10**

**Maintenance Actions Performed and Costs for Component Group, 7-Year Summary**

| Component Group | Description | Maintenance/Repair Actions: CBU | | Maintenance/Repair Actions: MHU | | Cost ($): CBU | | Cost ($): MHU | | MHU Adjusted |
|---|---|---|---|---|---|---|---|---|---|---|
| | | (N=13,052) | | (N=21,093) | | (Total = 448,326) | | (Total = 853,168) | | (Total = 614,281) |
| 0101-0105 | Roofing | 374 | (3%) | 665 | (3%) | 13,161 | (3%) | 36,016 | (4%) | 25,932 |
| 0201-0220 | Structure | 4,271 | (33%) | 5,707 | (27%) | 88,516 | (20%) | 137,007 | (16%) | 98,645 |
| 0301-0305 | Floor coverings | 82 | (1%) | 437 | (2%) | 2,648 | (1%) | 28,240 | (3%) | 20,333 |
| 0401-0405 | Interior painting | 544 | (4%) | 888 | (4%) | 155,668 | (35%) | 269,914 | (32%) | 194,338 |
| 0501-0506 | Exterior painting | 10 | (0%) | 24 | (0%) | 274 | (0%) | 17,986 | (2%) | 12,950 |
| 0601-0608 | Heating | 797 | (6%) | 1064 | (5%) | 21,003 | (5%) | 26,153 | (3%) | 18,830 |
| 0701-0707 | Air conditioning | 1,209 | (9%) | 1,300 | (6%) | 46,077 | (10%) | 36,390 | (4%) | 26,201 |
| 0801-0809 | Plumbing | 2,165 | (17%) | 5,132 | (24%) | 43,006 | (10%) | 131,429 | (15%) | 94,629 |
| 0901-0908 | Electrical | 1,650 | (13%) | 1,942 | (9%) | 28,701 | (6%) | 42,138 | (5%) | 30,339 |
| 1001-1006 | Equipment | 1,620 | (12%) | 3,332 | (16%) | 41,416 | (9%) | 110,741 | (13%) | 79,734 |
| 1201-1205 | Utility service | 208 | (2%) | 333 | (2%) | 6,539 | (1%) | 14,154 | (2%) | 10,191 |
| 1300 | Miscellaneous | 122 | (1%) | 270 | (1%) | 1316 | (0%) | 3,000 | (0%) | 2,160 |

**Table 11**

**Water Piping Costs**

| Year | CBUs ($) | MHUs ($) |
|---|---|---|
| 1 | 776 | 1,134 |
| 2 | 473 | 2,524 |
| 3 | 408 | 758 |
| 4 | 408 | 1,769 |
| 5 | 108 | 2,462 |
| 6 | 487 | 4,870 |
| 7 | 557 | 12,036 |
| Total | 3,216 | 25,554 |

Most leaks are breaks of the "hard plastic" tees and valves, usually under the crimped metal band. The Fort Irwin DEH thinks it is so bad that they want to replace all piping. They are contracting the replacement in one building to develop the methods and to get a better idea of the cost. As this report is being written a special study of the problem is being initiated.

This is not a new problem in the plastic pipe industry. A "60 minutes" television program shown in December 1990, described many problems in the Southwest with such materials. The companies paid required repairs because the plastic material itself was defective. A question to be answered is whether the same defective material was used at Fort Irwin.

## Impact of Inflation on Comparisons

All of the costs in Table 10 were charged at the time of occurrence. There was about a 1-year difference between the two types of units since the CBUs were occupied about 1 year earlier than the MHUs. To assess the impact of inflation on the overall comparisons, costs were all converted to 1990 prices by multiplying total costs in a given year by that year's inflation factor. Inflation factors for the years 1983 through 1990 were determined from "The Home Maintenance and Repair Index" in the *Economic Report of the President* (Table B-59, Consumer Price Indexes, selected classes, 1946-1990, Jan 90). The yearly indices and inflation factors used in this study are shown below:

| Year | Index | Inflation Factor |
|---|---|---|
| 1991 | 126.0 (est) | 1.000 |
| 1990 | 122.2 | 1.031 |
| 1989 | 118.0 | 1.068 |
| 1988 | 114.7 | 1.099 |
| 1987 | 111.8 | 1.127 |
| 1986 | 107.9 | 1.168 |
| 1985 | 106.5 | 1.183 |
| 1984 | 103.7 | 1.215 |
| 1983 | 99.9 | 1.261 |

Figure 7 shows cumulative inflated costs per unit over time. This is the same graph as that in Figure 2, except that the costs are inflated. Note that the difference between the two types at the end of 5 years was about the same, but the magnitude of both had increased. This can also be seen in Table 12.

The difference for cost/unit/year is $160 for actual costs and $162 for inflated costs. Thus, there is no difference in the two comparisons.

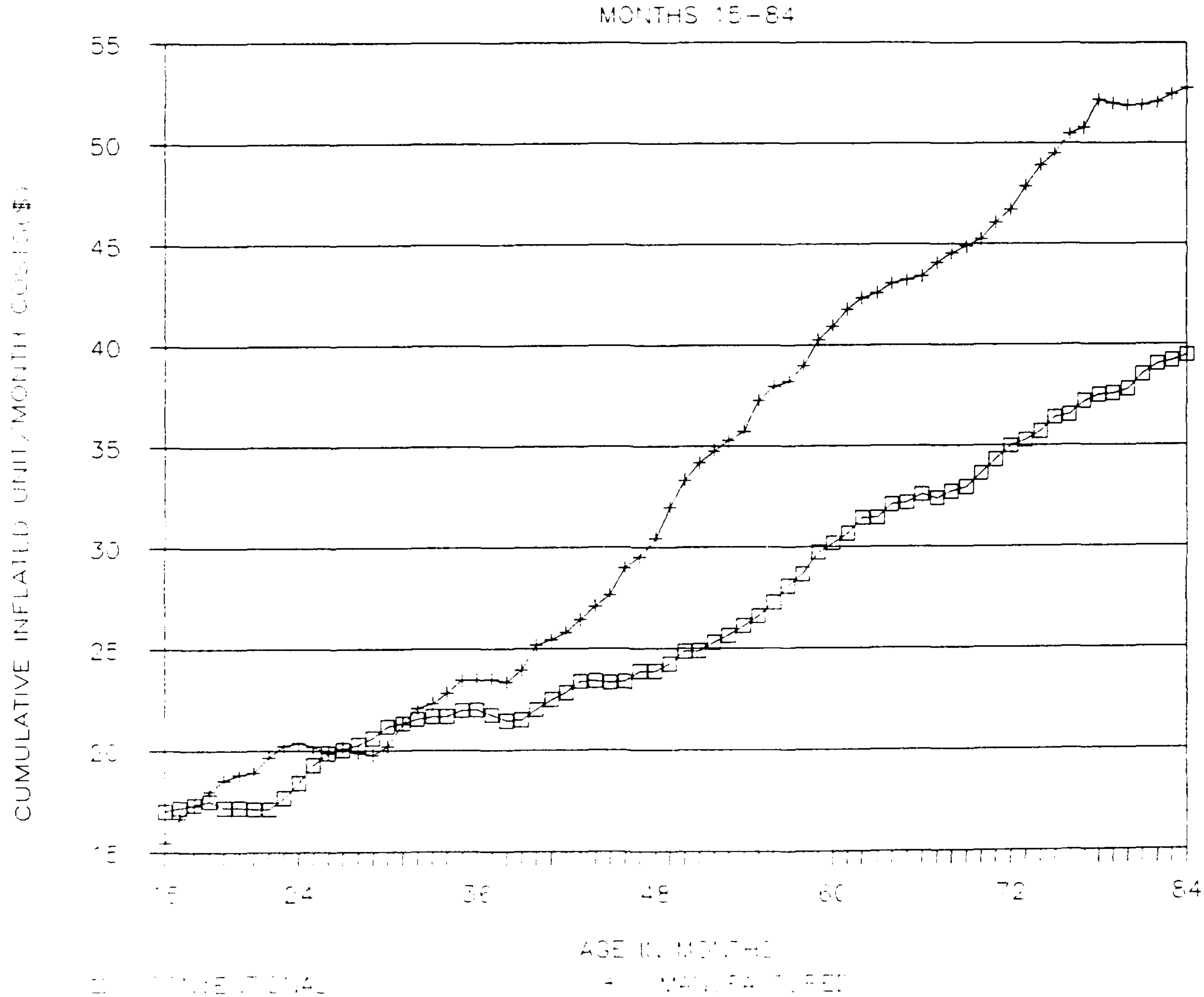


**Figure 7. Cost per unit per month over time, adjusted for inflation.**

**Table 12**

**Comparison of Actual and Inflated Costs**

| Type | No. Unit Months | Total Cost ($) | Cost/Unit/ Month ($) | Cost/Unit/ Year ($) |
|---|---|---|---|---|
| CBU | 12,096 | 448,326 | 37.06 | 445 |
| CBU-Infl | 12,096 | 497,568 | 41.13 | 494 |
| MHU | 16,800 | 853,168 | 50.78 | 609 |
| MHU-Infl | 16,800 | 918,437 | 54.67 | 656 |

# 7 ENERGY COSTS

Comparisons of gas and electricity consumption began in May 1984, since most MHUs were not occupied before then.

## Electricity Consumption

The average quarterly usage (kWh) per housing unit is shown in Table 13. The MHUs had higher average consumptions than the CBUs in 14 of the 28 quarters and always higher in the summer quarter, Jun-Aug. For the entire 84-month data collection period, an MHU used an average total of 64,072 kWh, while a CBU used an average total of 63,020 kWh. This was a difference of 1,052 kWh ÷ 84 months = 12.52 kWh/month. At the August 1991 rate of $0.0712/kWh, an MHU cost $0.89 more than a CBU for electricity per month.

## Gas Consumption

The type of fuel used was liquid propane (LP). LP is delivered to a central facility on post and is converted to gas and distributed to housing units through underground pipes. The average quarterly usage (cu ft) per housing unit is shown in Table 14.

For the 84-month period, an MHU used an average total of 136,560 cu ft while a CBU used an average total of 127,078 cu ft. The MHUs had higher average consumptions in 23 of the quarters, always higher in the winter, Dec-Feb,and spring, Mar-May, quarters. This is a difference of 9,482 cu ft ÷ 84 months = 113 cu ft/month. At the August 1991 cost of $0.01446/cu ft an MHU cost $1.63 more than a CBU for gas per month.

## Total Energy Consumption

The total energy consumption for the housing units is shown in Table 15. It was calculated by converting the gas and electricity consumption data to MBTU/KSF. (One cubic foot of propane gas = 2618.5 BTU and one kWh of electricity = 3413 BTU.) The area of the housing units is approximately 950 sq ft, so a multiplier of 1000/950 = 1.053 was used to convert usage to kilowatts per square foot.

## Cost Comparison Summary

The averages for dwelling unit energy consumption and cost for the 7-year period (May 1984 to April 1991) are given in Table 16. The MHUs on the average have cost $30 more per year for gas and electricity than the CBUs.

## Meter Problems

Many meters have become defective over the past 7 years. For the CBUs 39 electric and nine gas meters have failed while for the MHUs 19 electric and four gas have failed.

**Table 13**

**Average Quarterly Electricity Consumption (kWh) Per Housing Unit**

| | 1984 Jun-Aug | Sep-Nov | 1984-5 Dec-Feb | 1985 Mar-May | Jun-Aug | Sep-Nov | 1985-6 Dec-Feb | 1986 Mar-May |
|---|---|---|---|---|---|---|---|---|
| MHU | 3492 | 2005 | 1399 | 1737 | 4053 | 1743 | 1470 | 1763 |
| CBU | 3263 | 1925 | 1353 | 1655 | 3752 | 1857 | 1410 | 1738 |

| | 1986 Jun-Aug | Sep-Nov | 1986-7 Dec-Feb | 1987 Mar-May | Jun-Aug | Sep-Nov | 1987-8 Dec-Feb | 1988 Mar-May |
|---|---|---|---|---|---|---|---|---|
| MHU | 3951 | 1778 | 1500 | 1725 | 3644 | 2191 | 1483 | 1702 |
| CBU | 3683 | 1934 | 1630 | 1813 | 3550 | 2411 | 1494 | 1768 |

| | 1988 Jun-Aug | Sep-Nov | 1988-9 Dec-Feb | 1989 Mar-May | Jun-Aug | Sep-Nov | 1989-90 Dec-Feb | 1990 Mar-May |
|---|---|---|---|---|---|---|---|---|
| MHU | 3738 | 2366 | 1550 | 1996 | 3892 | 2192 | 1523 | 1750 |
| CBU | 3513 | 2445 | 1610 | 2024 | 3634 | 2180 | 1478 | 1823 |

| | 1990 Jun-Aug | Sep-Nov | 1990-1 Dec-Feb | 1991 Mar-May |
|---|---|---|---|---|
| MHU | 3796 | 2349 | 1467 | 1624 |
| CBU | 3404 | 2252 | 1600 | 1730 |

Table 14

**Average Quarterly Gas Consumption (1 cu ft) Per Housing Unit**

| | 1984 Jun-Aug | Sep-Nov | 1984-5 Dec-Feb | 1985 Mar-May | Jun-Aug | Sep-Nov | 1985-6 Dec-Feb | 1986 Mar-May |
|---|---|---|---|---|---|---|---|---|
| MHU | 1890 | 4400 | 10050 | 5130 | 1890 | 4440 | 7670 | 4020 |
| CBU | 1780 | 3730 | 9200 | 4500 | 1840 | 3970 | 7080 | 3950 |

| | 1986 Jun-Aug | Sep-Nov | 1986-7 Dec-Feb | 1987 Mar-May | Jun-Aug | Sep-Nov | 1987-8 Dec-Feb | 1988 Mar-May |
|---|---|---|---|---|---|---|---|---|
| MHU | 1800 | 3810 | 9340 | 4390 | 1910 | 3300 | 9930 | 4740 |
| CBU | 2130 | 3520 | 9070 | 4500 | 2160 | 3430 | 9500 | 4460 |

| | 1988 Jun-Aug | Sep-Nov | 1988-9 Dec-Feb | 1989 Mar-May | Jun-Aug | Sep-Nov | 1989-90 Dec-Feb | 1990 Mar-May |
|---|---|---|---|---|---|---|---|---|
| MHU | 1880 | 3490 | 10000 | 3700 | 1940 | 3370 | 9150 | 4010 |
| CBU | 1960 | 3250 | 9400 | 3550 | 1960 | 3140 | 8160 | 3390 |

| | 1990 Jun-Aug | Sep-Nov | 1990-1 Dec-Feb | 1991 Mar-May |
|---|---|---|---|---|
| MHU | 1850 | 3350 | 9210 | 6070 |
| CBU | 1790 | 2920 | 7810 | 4950 |

Table 15

**Total Energy Consumption**

| | MHU Elect | MHU Gas | CBU Elect | CBU Gas |
|---|---|---|---|---|
| 84 month total | 64,072 kWh | 136,560 CF | 63,020 kWh | 127,078 CF |
| Yearly average | 9,153 kWh | 19,509 CF | 9,003 kWh | 118,154 CF |
| MBTU/year | 31.24 | 51.08 MBTU | 30.73 MBTU | 47.54 MBTU |
| Total energy per year | 82.32 MBTU | | 78.27 MBTU | |
| Conversion to MBTU/ksq ft | 86.68 MBTU/yr | | 82.41 MBTU/yr | |

(MBTU = million British thermal units, CF = cubic feet)

**Table 16**

**Seven-Year Summary of Energy Consumption**

| Unit | MHU Gas | MHU Electricity | CBU Gas | CBU Electricity |
|---|---|---|---|---|
| Average Consumption/Year Per Housing Unit | 19,509 | 9,153 kWh | 18,154 cu ft | 9,003 kWh |
| Average Cost/Year Per Housing Unit | $282 | $652 | $263 | $641 |
| Total Cost/Year | $934 | | $904 | |

## Comments

The data in Chapter 5 (better air tightness and higher furnace efficiencies for the MHUs) would indicate the MHUs should use less energy than the CBUs. However, this is offset by the higher overall heat loss of the MHUs. Detailed energy simulations (performed using the Building Loads Analysis and System Thermodynamics* program) indicate two design/construction features that cause the higher wall-heat loss: the MHUs have more window/door glass area; and the MHUs have single-pane glass while the CBUs have thermal-pane. Additionally, the CBUs were built on concrete slabs while the MHUs have crawl spaces, which are less energy efficient.

*The Building Loads Analysis and System Thermodynamics (BLAST) program was developed by USACERL and is used throughout the Department of Defense for military construction projects.

# 8 CONCLUSIONS AND RECOMMENDATIONS

## Maintenance Costs

After 7 years' occupancy, there is a difference in maintenance costs between the two types of units. The MHUs cost $122 more per unit for maintenance (ignoring equipment costs, such as ranges and dishwashers). This is a 30.5 percent difference in costs ($522/year for MHU vs. $400/year for CBU).

## Energy Costs

MHUs cost more than CBUs for energy used—$30 more per unit per year for gas and electricity.

## Total O&M Costs

The total difference in O&M costs is $152/year/unit (11.7 percent) (based on $1304/year for CBUs ignoring equipment costs.)

The maintenance cost difference of 30.5 percent, combined with the overall trend for MHU costs to increase at a faster rate, indicates that the maintenance cost difference may well become very large.

## Trends

A problem is developing with the MHU water piping. Piping failures are not only significantly increasing in cost, but also in impacting the morale of families in units with major problems. If all piping has to be replaced there will be a very significant difference to the government in costs between the two types of construction.

It is recommended data collection continue for another year, and that the causes of the MHU water piping problem and the resultant cost to the government be investigated.

## APPENDIX A: DESCRIPTION OF THE MHU CONSTRUCTION PROCESS

The MHUs were not typical of manufactured housing in that the manufacturer was not allowed to design the housing. Instead the contractor was given designs based on the fourplexes being built using conventional construction methods and was required to manufacture accordingly. Thus, it is possible that given the opportunity to both design and manufacture, the final structure might be somewhat different and less costly.

The concept used was to manufacture complete modules in the factory which could be transported (about 200 miles from the factory in the Los Angeles area to Fort Irwin) and assembled on site. Thus, the process involved several steps: manufacture of complete modules (electrical, plumbing, HVAC, etc., included at the plant); construction of perimeter footings at the site; transportation of modules to the site; assembly of the modules into fourplexes using a crane; joining modules together including connection of piping and electrical wiring; application of stucco exterior finish; roofing at the module joints and securing of eaves; and on-site construction of the garages. On-site construction was limited by contract to foundations, utilities, slabs, garages, exterior finishes, final painting, exterior stairways and balconies. Figures A1 through A6 show factory work, modules on trucks, crane assembly and a completed fourplex without stucco and garages.

As is discussed in Chapter 10, the eaves were attached using flat metal straps and folded onto the roof for transportation (this decreased the width for highway transportation). Upon assembly at the site, the eaves were folded down and secured with only a few nails. This was a defect in the design/construction, as the eaves began to loosen and one actually fell to the ground. All eaves were then permanently secured at a cost of over $6000 per building.

The MHUs are essentially the same as the CBUs; floor plans of the two types are very similar. Figures A7 through A10 show sample floor plans for the MHUs and the CBUs.

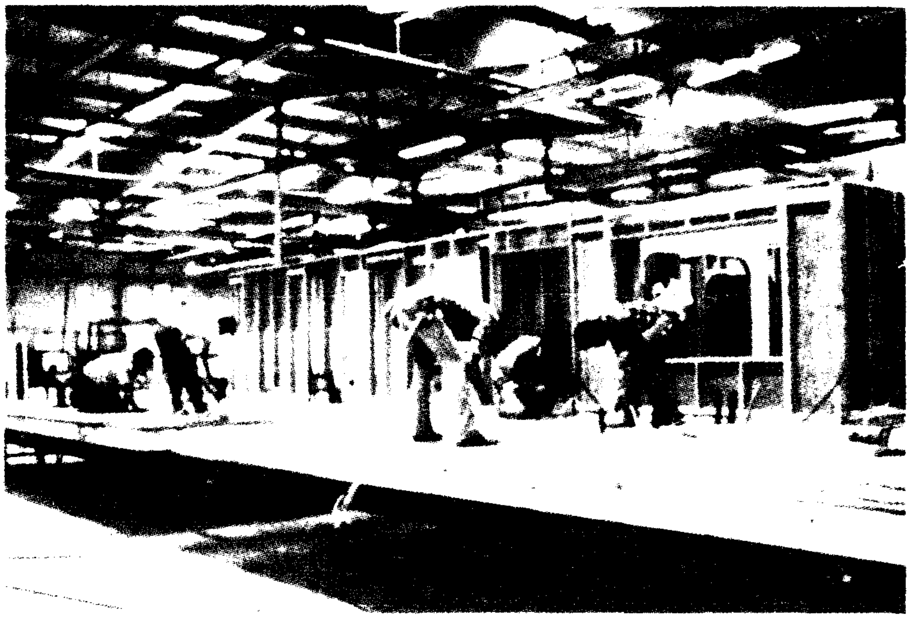

Figure A1. Construction in the factory.

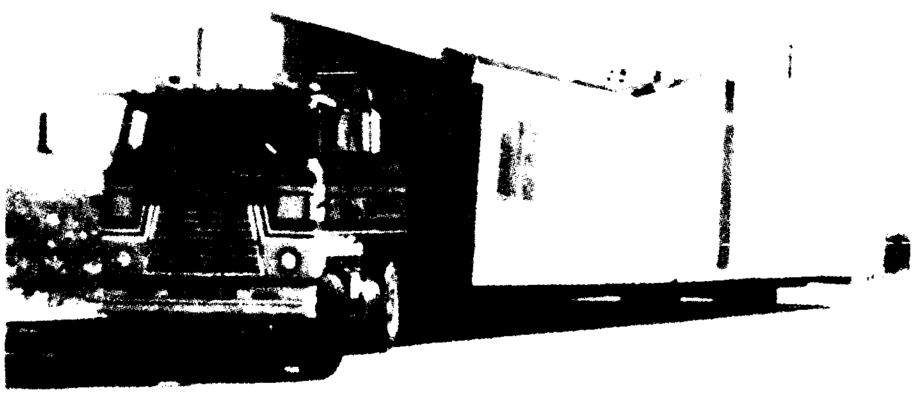

Figure A2. Two modules loaded on truck.

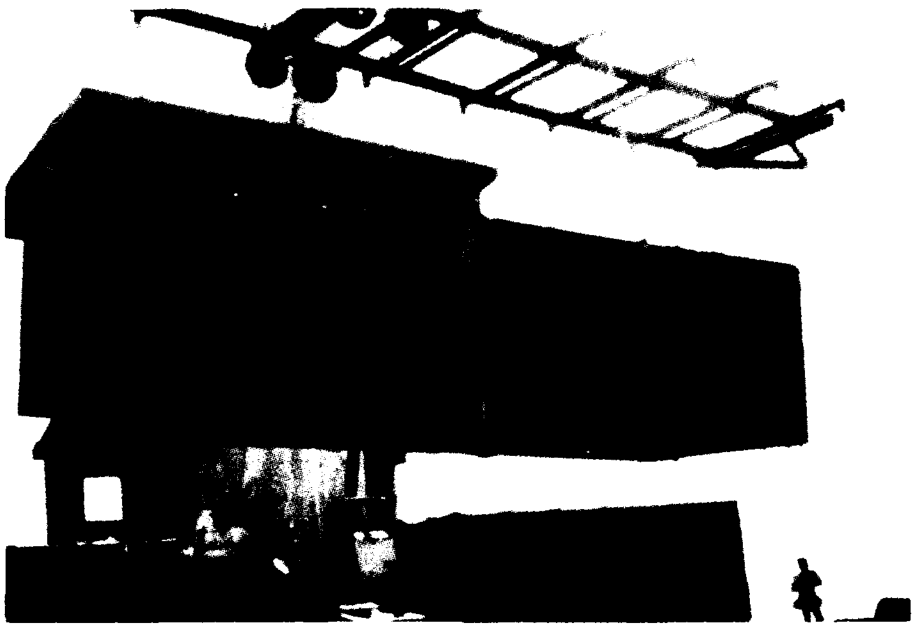

Figure A3. Module being set in place by crane.

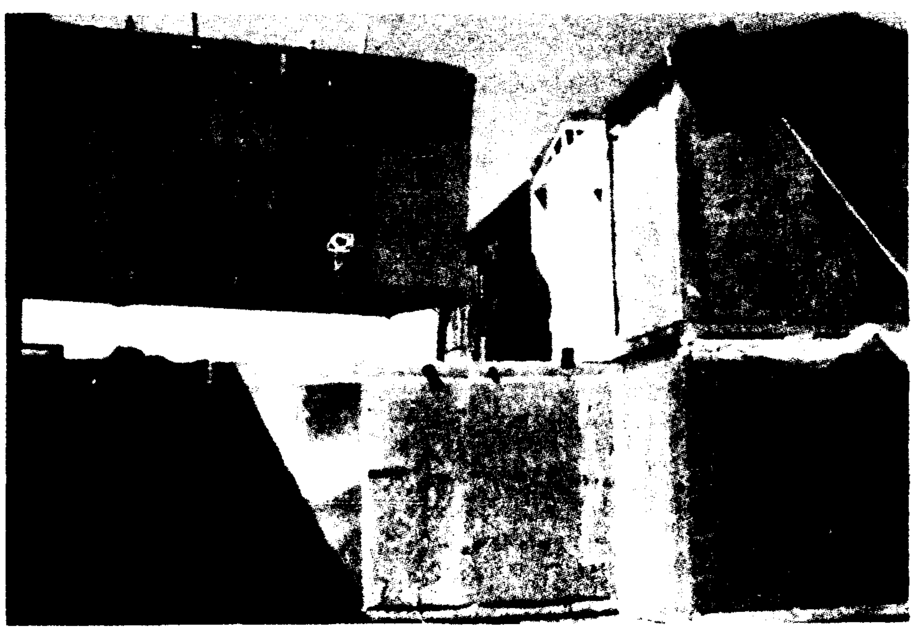

Figure A4. Near completion of one building.

Figure A5. Completed assembly of modules.

Figure A6. Overview of buildings without garages.

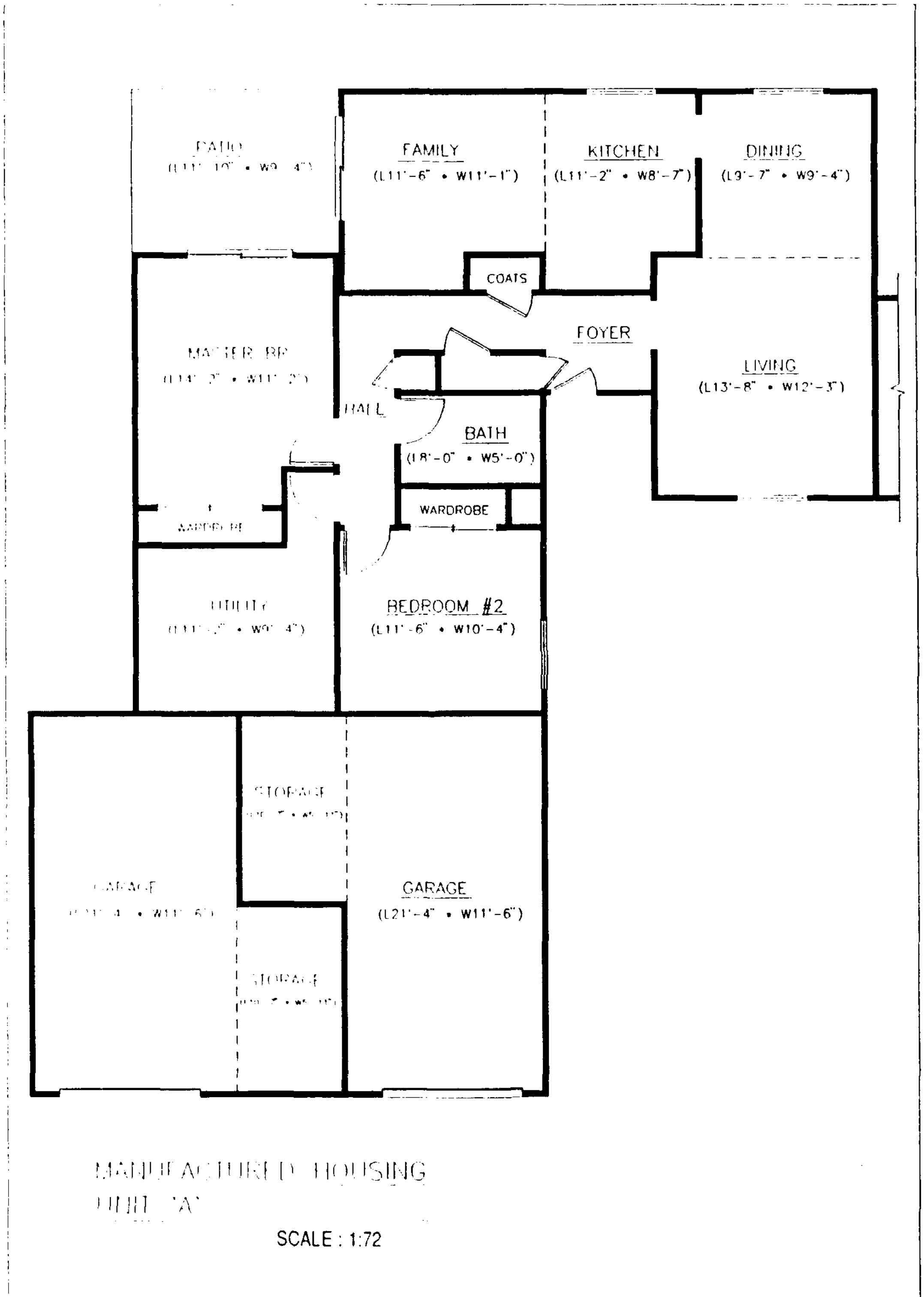


**Figure A7. Floor plan for first floor MHU, Type A.**

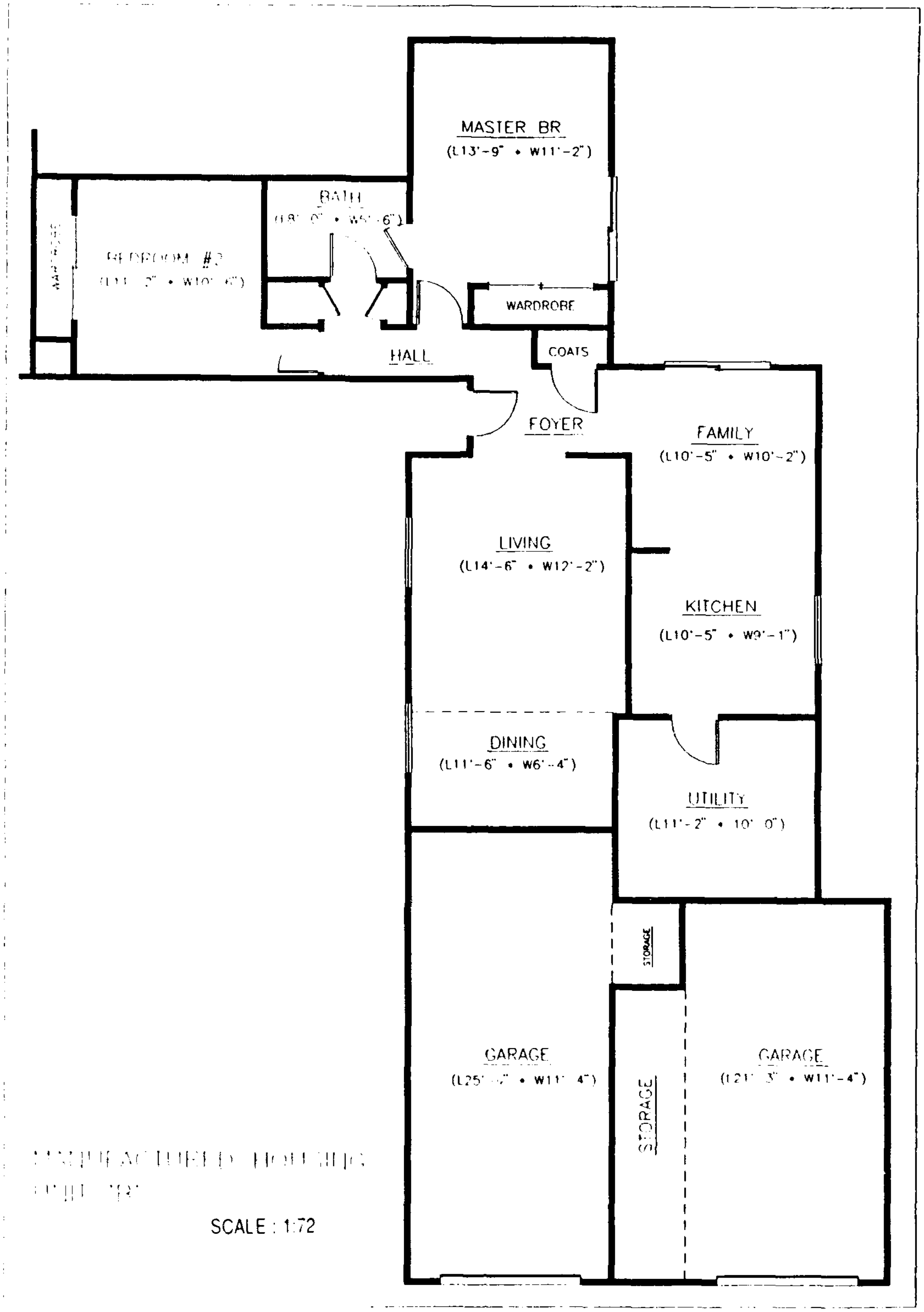


**Figure A8. Floor plan for first floor MHU, Type B.**

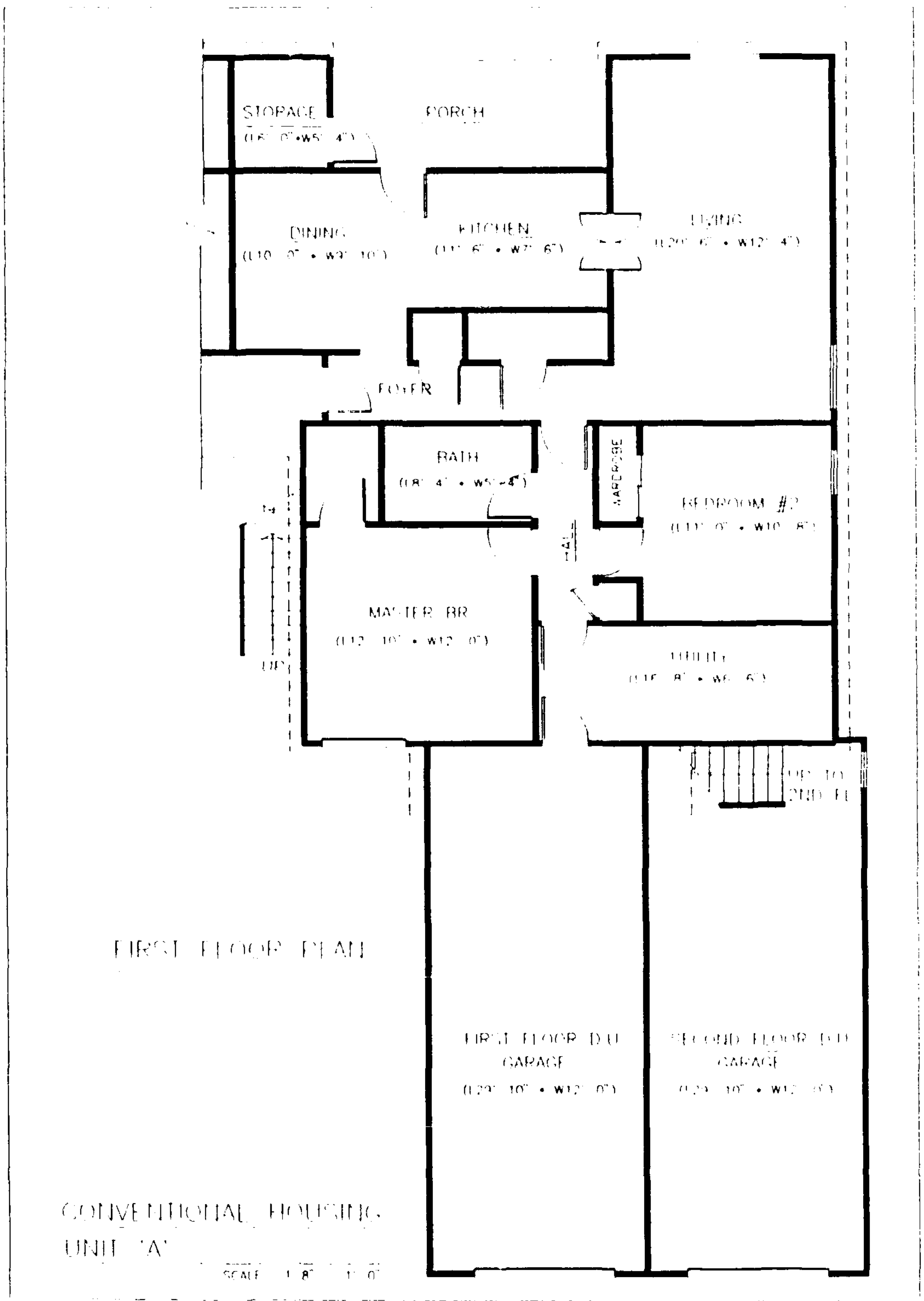


**Figure A9. Floor plan for first floor CBU, Type A.**

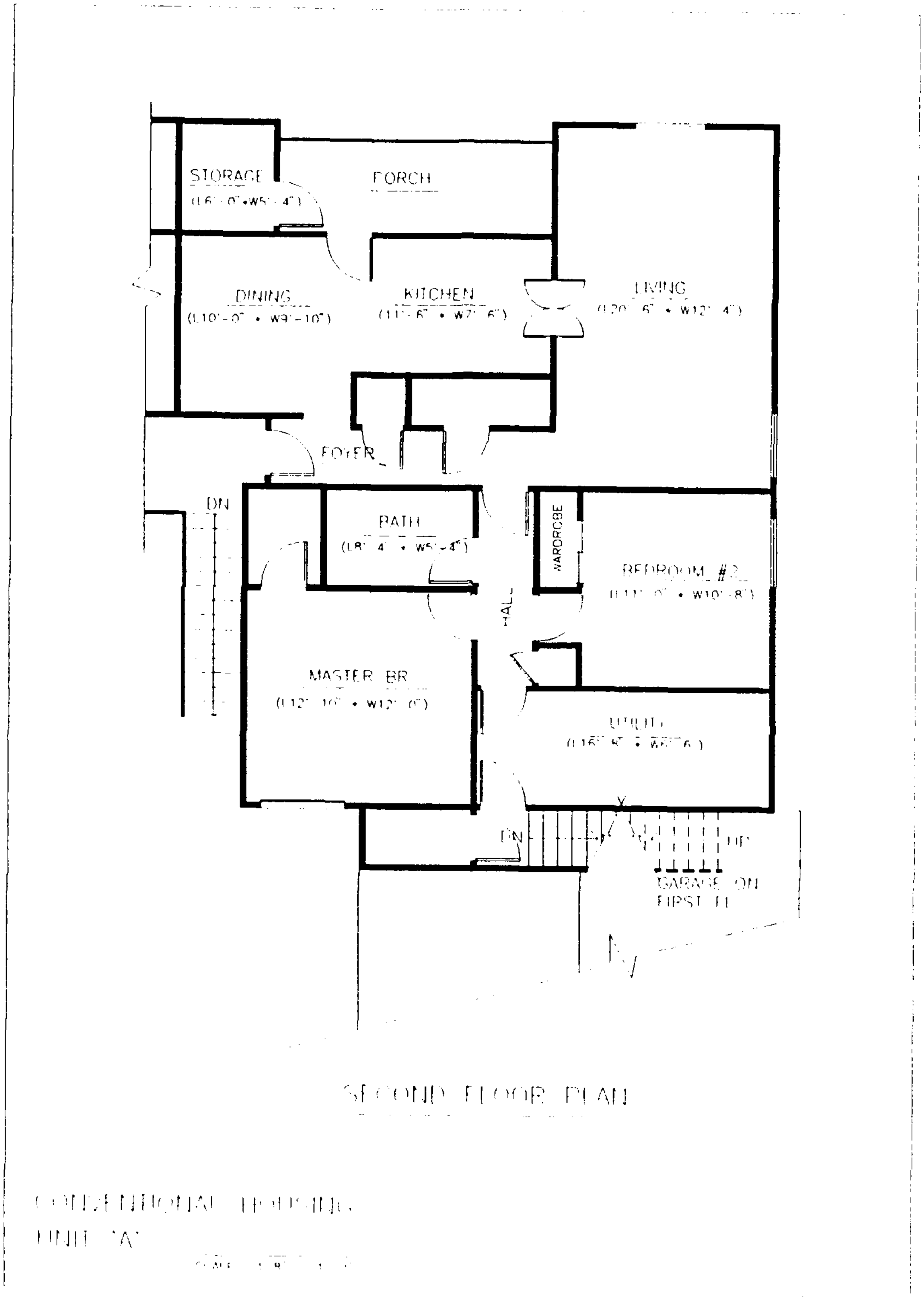


**Figure A10. Floor plan for second floor CBU, Type A.**

## APPENDIX B: LIST OF HOUSING UNITS

### Conventionally Built

| | | |
|---|---|---|
| 3680 A-F | 3705 A-E | 3727 A-E |
| 3681 A-D | 3712 A-F | 3731 A-D |
| 3684 A-D | 3715 A-F | 3732 A-F |
| 3685 A-F | 3720 A-F | 3738 A-F |
| 3690 A-F | 3721 A-E | 3742 A-D |
| 3691 A-D | 3722 A-E | 3743 A-F |
| 3693 A-F | 3723 A-E | 3745 A-F |
| 3694 A-D | 3724 A-D | 3747 A-D |
| 3695 A-D | 3725 A-E | 3750 A-F |
| 3700 A-F | | |

**Manufactured** (Each with four apartments, A-D)

| | | |
|---|---|---|
| 3800 | 3821 | 3841 |
| 3801 | 3822 | 3842 |
| 3802 | 3823 | 3843 |
| 3803 | 3824 | 3844 |
| 3804 | 3825 | 3845 |
| 3805 | 3826 | 3846 |
| 3806 | 3827 | 3848 |
| 3807 | 3828 | 3850 |
| 3809 | 3829 | 3851 |
| 3811 | 3831 | 3852 |
| 3812 | 3832 | 3853 |
| 3813 | 3833 | 3854 |
| 3814 | 3834 | 3855 |
| 3815 | 3835 | 3856 |
| 3816 | 3837 | 3857 |
| 3818 | 3839 | 3858 |
| 3820 | 3840 | |

## APPENDIX C: BUILDING COMPONENT/SUBCOMPONENT CODES

### 01 Roofing

| | |
|---|---|
| 0101 | Roofing surface |
| 0102 | Fasteners |
| 0103 | Flashing, vents, protrusions |
| 0104 | Gutter and downspouts |
| 0105 | Other roof repairs |

### 02 Structure

| | |
|---|---|
| 0201 | Foundation and anchorage |
| 0202 | Structure, incl. framing and sheathing, stairs, cracked wall |
| 0203 | Insulation and moisture protection |
| 0204 | Masonry |
| 0205 | Exterior siding, incl. skirting |
| 0206 | Exterior doors and frames, incl. hardware and weatherstripping |
| 0207 | Storm and screen doors |
| 0208 | Window and frames, incl. hardware and weatherstripping |
| 0209 | Storm windows and screens |
| 0210 | Exterior trim |
| 0211 | Porch/deck construction |
| 0212 | Interior drywall, incl. fasteners and accessories |
| 0213 | Wall coverings and paneling |
| 0214 | Interior doors, frames, and hardware, incl. bifold and sliding |
| 0215 | Interior casework and finish carpentry |
| 0216 | Bathroom accessories, mirror |
| 0217 | Kitchen accessories, cabinets |
| 0218 | Drapery hardware |
| 0219 | Other exterior/interior repair, venetian blinds |
| 0220 | Garage door |

### 03 Floor Coverings

| | |
|---|---|
| 0301 | Resilient flooring |
| 0302 | Carpet and pad |
| 0303 | Ceramic flooring |
| 0304 | Underlayment/substrate |
| 0305 | Other flooring repairs |

### 04 Interior Painting

| | |
|---|---|
| 0401 | Walls and ceilings, incl. patching |
| 0402 | Trim |
| 0403 | Touch-up |
| 0404 | Bathtub/shower unit caulking |
| 0405 | Other Interior painting |

## 05 Exterior Painting

| | |
|---|---|
| 0501 | Walls, siding, incl. skirting |
| 0502 | Doors, frames, trim |
| 0503 | Exterior trim, incl. window, fascia, rake, soffit, etc. |
| 0504 | Caulking and sealing |
| 0505 | Glazing |
| 0506 | Other exterior painting |

## 06 Heating

| | |
|---|---|
| 0601 | Heating plant, valve |
| 0602 | Motors, blowers, pumps, G-60 |
| 0603 | Ducts |
| 0604 | Piping |
| 0605 | Diffusers, grills |
| 0606 | Insulation |
| 0607 | Heating controls |
| 0608 | Other heating repairs, instructions for thermostat, turn on gas |

## 07 Air Conditioning

| | |
|---|---|
| 0701 | Cooling coils, compressor, condenser, valve, contactor |
| 0702 | Motors, blowers, pumps, transformer, fuses |
| 0703 | Piping, ducting |
| 0704 | Refrigerant |
| 0705 | Insulation |
| 0706 | Controls, delay module, relay |
| 0707 | Other cooling repairs, instruct thermostat use, filter |

## 08 Plumbing

| | |
|---|---|
| 0801 | Water heater |
| 0802 | Water softener |
| 0803 | Piping, supply, incl. valves, arrestors |
| 0804 | Faucets and shower heads |
| 0805 | Lavatories, incl. support and fasteners, caulking |
| 0806 | Water closets (i.e., toilets and commodes), incl. support and seals, caulking |
| 0807 | Bathtub/shower unit |
| 0809 | Other plumbing repair |

## 09 Electrical

| | |
|---|---|
| 0901 | Service entrance |
| 0902 | Panel box, incl. circuit breakers |
| 0903 | Branch circuits, incl. junctions, fasteners |
| 0904 | Wall receptacles and switches |

| | |
|---|---|
| 0905 | Doorbells, chimes |
| 0906 | Light fixtures |
| 0907 | Vents, fans |
| 0908 | Other electrical repair |

**10 Equipment**

| | |
|---|---|
| 1001 | Disposal |
| 1002 | Dishwasher |
| 1003 | Stove, range |
| 1004 | Range hood |
| 1005 | Refrigerator |
| 1006 | Other equipment |

**11 Utility Plant Equipment**

Not applicable

**12 Utility Service**

| | |
|---|---|
| 1201 | Water supply |
| 1202 | Gas supply |
| 1203 | Electrical service |
| 1204 | Sanitary/sewer |
| 1205 | Other utility service |

**13 Miscellaneous**

## APPENDIX D: ENERGY EFFICIENCY TESTS OF 15 CONVENTIONALLY BUILT HOUSING UNITS

The objective of these tests was to provide data concerning the energy efficiency of conventionally built housing. Tests were performed to determine the airtightness of the units (a measure of the resistance to air infiltration), furnace efficiencies, and heat transfer characteristics of the building envelope.

### I. Tests Performed Upon Completion of Construction

Tests were conducted over 4 days in June 1983 on three types of buildings: a fourplex, a fiveplex, and a sixplex. Weather conditions were typical of the high desert area: light to negligible winds, clear skies, low humidity, and temperatures ranging from lows near 70 °F to highs near 110 °F.

#### House Tightness

A blower door apparatus was used to measure each unit's tightness. The blower door consisted of a variable speed fan, a digital tachometer to measure the fan blade rotation speed, and an inclined manometer to measure pressure differences. The fan could be operated to induce a positive or negative pressure difference in the house with respect to the outdoors.

To perform this test, the fan was fitted tightly into an outside door frame. A barbed fitting which penetrates the blower door was fitted with rubber tubing and connected to one side of the manometer. The other side of the manometer was open to the house. When the fan was operated, it could either force air into the house (pressurized) or force air out of the house (depressurized) depending on the direction of rotation. In either case, the pressure difference between the house and the outdoors could be read on the manometer. The fan speed was adjusted until a specified pressure difference existed (usually 0.1 or 0.2 in. of water). The fan speed required to achieve a given pressure was correlated to air flow, which indicated how tightly the house was sealed.

Each of the units was tested at 0.1 and 0.2 in. $H_2O$ pressurized, and 0.2 in. $H_2O$ depressurized. Some of the more obvious leaks (furnace room doors, dryer vents, attic doors) were then taped, and the house was again tested at 0.2 in. $H_2O$ depressurized.

As shown in Table D1, airtightness was adequate, requiring no corrective work.

#### Furnace Efficiency

The furnaces in all the units were propane-fired. Tests were performed with a Fuel Efficiency Monitor (FEM), a hand-held automatic flue gas analyzer which measures the flue gas temperature, oxygen content, and ambient conditions and uses this information to calculate and display the percent efficiency of the furnace.

Each housing unit was first cooled down to allow the furnace to operate. The thermostats in the houses were of the "energy-saving" type, and included night setback and temperature limits. These were disconnected before each test so that the heating and air conditioning could be manually adjusted. The safety relief on the front of each furnace was covered so that room air would not be introduced into the flue. The furnace was then turned on, and a sample was taken of the intake air using the FEM. A 1/8-in.

Table D1

CBU Energy Efficiency Data After Construction

| Building/Unit | UA* Btu/Hr-°F | No. Air Changes** Per Hour | Furnace*** Efficiency (%) |
|---|---|---|---|
| 3720A | 213 | 11.4 | 52.6 |
| 3720B | 181 | 12.1 | 61.3 |
| 3720C | 181 | 13.1 | 62.8 |
| 3720D | 213 | 12.8 | 67.2 |
| 3720E | 304 | 12.4 | 71.7 |
| 3720F | 304 | 13.2 | 73.0 |
| 3724A | 181 | 11.8 | 61.9 |
| 3724B | 181 | 13.3 | 62.6 |
| 3724C | 304 | 13.0 | 71.4 |
| 3724D | 304 | 15.1 | 72.3 |
| 3725A | 181 | 11.7 | 61.6 |
| 3725B | 181 | 12.8 | **** |
| 3725C | 213 | 13.9 | 69.3 |
| 3725D | 304 | 13.4 | 72.7 |
| 3725E | 304 | 14.8 | **** |

*These are calculated values based on the wall construction. U=heat transfer; A = area
**The following rating of air changes per hour at 0.2in. water column is based on work currently being done by Mansville Corp. for the U.S. Navy; 0 to 5, objectively tight; 5 to 10, excellent; 10 to 15, satisfactory; 15 and above merits corrective work.
***Most gas fired furnace manufacturers claim 80 percent efficiency.
****Unable to test furnace due to lack of access to the units.

hole was then drilled in the flue of the furnace. After allowing a few minutes for the furnace to reach steady state, the FEM probe was inserted into the flue pipe and a sample was taken of the exhaust gas. The FEM took 2 to 3 min to calculate the furnace efficiency.

Table D1 shows the furnaces' operational efficiencies.

## Wall Heat Transfer Characteristics

A Thermo Flow Energy Meter (TEM) was obtained to test the heat transfer characteristics of the walls. The TEM is an infrared radiometer which displays heat flow digitally in units of Btu/hr/sq ft. It can be used to detect insulation defects and to estimate the thermal resistance of exterior walls.

Due to unfavorable weather, the TEM could not be used to calculate R-values. The device was also useful for detecting insulation voids. No insulation voids were found.

## II. Tests Performed after Five Years' Occupancy

The house tightness and furnace efficiency tests were performed again in May 1988. Results are summarized below in Table D2.

Again, no wall insulation tests were performed because of weather conditions.

**Table D2**

**CBU Energy Efficiency Data 5 Years After Construction**

| Unit No. | No. Air Changes Per Hour | Furnace Efficiency (%) |
|---|---|---|
| 3720A | 11.0 | 58.5 |
| 3720B | 11.4 | 68.6 |
| 3720C | 12.9 | 65.8 |
| 3720D | 10.2 | 70.6 |
| 3720E | 10.6 | 74.2 |
| 3720F | 10.8 | 59.5 |
| 3724A | 10.6 | 68.9 |
| 3724B | 11.6 | 57.8 |
| 3724C | 14.4 | 67.4 |
| 3724D | 12.3 | 70.4 |
| 3725A | 11.3 | 66.0 |
| 3725B | 11.8 | 24.1 |
| 3725C | 14.4 | 68.8 |
| 3725D | 16.2 | 67.3 |
| 3725E | 12.4 | 74.5 |

# APPENDIX E: ENERGY EFFICIENCY TESTS OF 16 MANUFACTURED HOUSING UNITS

The objective of these tests was to provide data on the energy efficiency of manufactured housing units which will be compared to existing energy efficiency data taken on conventionally built housing units. Tests were performed to determine the airtightness of the units (a measure of the resistance to air infiltration), furnace efficiencies, and heat transfer characteristics of the building envelope.

## I. Tests Performed Upon Completion of Construction

Tests were conducted on three types of fourplexes; Type I (Building 3809), II (Building 3802), and IV (Buildings 3800 and 3806). The tests were conducted over 4 days in April 1984. The weather during the testing was mild for high desert area; medium to strong winds, overcast skies, low humidity, and temperatures ranging from morning lows of 40 $^{o}$F to highs near 80 $^{o}$F.

### House Tightness

To measure the tightness of each housing unit a blower door apparatus was used, as described in Appendix D.

Each of the manufactured housing units was tested at 0.1, 0.2, and 0.3 in. of water during pressurization and then tested at 0.1 and 0.2 in. under depressurization. Then air leaks were taped (furnace doors and kitchen vents) and the unit was retested at 0.2 in. during pressurization. During the final day the winds were gusting so high that no consistent manometer reading could be taken, so Building 3809 had no data for air infiltration.

The results of the USACERL testing, as presented in Table E1, demonstrate that the airtightness of all the units except one is acceptable. Unit 3800-C had a significantly higher value than the other units and should have corrective work done to improve its tightness.

During the airtightness testing, several leaks were found. In Type II, Unit 3802-C, serious leaks were found in the door to the furnace room. In Type IV, Units 3800 and 3806, leaks were found while depressurizing around the furnace vents and doors (Unit A in both buildings). Also, leaks were found around sliding doors (Unit 3800-C), kitchen window area (Unit 3806-D), utility outlets (Unit 3800-D), and a crack in the dining room wall (Unit 3806-D).

### Furnace Efficiency

The furnaces in all of the units were propane-fired. Tests were performed using a FEM, as described in Appendix D. A carbon monoxide meter similar to the FEM was used to ensure that each furnace's burner was completely combusting its fuel and that there was no unusual concentration of carbon monoxide.

Table E1

**MHU Energy Efficiency Data After Construction**

| Building/Unit | UA* Btu/Hr-°F | No. Air Changes Per Hour | Furnace Efficiency (%) |
|---|---|---|---|
| 3800A | 296 | 9.9 | 75.5 |
| 3800B | 296 | 11.5 | 81.8 |
| 3800C | 363 | 18.4 | 80.5 |
| 3800D | 363 | 11.3 | 82.6 |
| 3802A | 271 | 9.0 | 70.1 |
| 3802B | 271 | 10.1 | 75.1 |
| 3802C | 370 | 12.1 | 81.8 |
| 3802D | 370 | 11.3 | 80.3 |
| 3806A | 296 | 8.0 | 78.2 |
| 3806B | 296 | 9.8 | 77.4 |
| 3806C | 363 | 8.7 | 80.7 |
| 3806D | 363 | 10.6 | 82.2 |
| 3809A | 249 | ** | 80.0 |
| 3809B | 249 | ** | 82.0 |
| 3809C | 336 | ** | 80.7 |
| 3809D | 336 | ** | 79.6 |

*These are calculated based on the wall construction. U = heat transfer coefficient; A = area.
**Unable to test airtightness due to high winds.

The testing was performed in the early morning hours so there would be a low outdoor temperature to start the furnace. The safety relief on the front of each furnace was taped over to prevent room air from entering the flue. A 1/8-in. hole was drilled into the flue near the furnace. The furnace was turned on and a sample of the ambient air was taken. The furnace was then left to reach steady state (approximately 15 min) and then the FEM probe was inserted into the hole and a sample of the exhaust gas was taken. The FEM took approximately 2 to 3 min to calculate and display the efficiency. Three samples were taken to ensure furnace steady state. The hole in the flue was then taped closed.

The furnace efficiencies are typical for the size and type of furnace installed.

## Wall Heat Transfer Characteristics

A TEM, as described in Appendix D, was used to test the heat transfer characteristics of the exterior walls of each unit and to detect insulation defects.

This testing was done in the early morning hours because there must be a constant temperature difference of at least 20 °F between outdoor and indoor temperatures. First the outdoor and indoor temperatures were taken until they appeared steady; next the TEM was aimed at an interior wall and the net heat flow reading was recorded. Then the TEM was aimed at an exterior wall and the heat flow through the wall was recorded. Finally the same measurement was made on the outside of the exterior wall (being sure that the area was shaded from sunlight). These results were used in conjunction with a standardized chart to determine the wall's thermal resistance. After these measurements were taken, the TEM was used to detect areas of high net flow readings, which indicate areas of insulation defects. There appear to be a number of insulation voids in Type I, II, and IV Units.

The UA values were calculated for the units, representing the overall heat transfer for the unit inclusive of walls, windows, doors, and roof (heat transferred from one unit to the next unit was considered negligible). The insulation voids listed in Table E2 were determined when the net heat flow varied by 10 Btu/hr-°F.

## II. Tests Performed After Five Years' Occupancy

The house tightness and furnace efficiency tests were performed again 5 years after construction. Results are given in Table E3.

**Table E2**

**Insulation Void Locations**

| Building/Unit | Location of Void |
|---|---|
| 3802A | Void area at upper left corner of window in front bedroom. |
| 3802C | Void area above sliding glass door in dining room. |
| 3802D | Void area at right electrical outlet in dining room. |
| 3806C | Void areas in all wall-to-wall seams (corners). |
| 3806D | Void areas in all wall-to-wall seams (corners). |
| 3809B | Void area at upper right corner of sliding glass door in dining room. |

Table E3

MHU Energy Data 5 Years After Construction

| Building/Unit | No. Air Changes Per Hour | Furnace Efficiency (%) |
|---|---|---|
| 3800A | 7.8 | 75.9 |
| 3800B | 9.4 | 80.2 |
| 380c0 | * | 76.3 |
| 3800D | 10.2 | 72.8 |
| 3802A | 9.6 | 71.2 |
| 3802B | 10.2 | 80.4 |
| 3802C | 10.8 | 79.1 |
| 3802D | * | * |
| 3806A | 8.6 | 79.9 |
| 3806B | 10.3 | 77.1 |
| 3806C | 11.4 | 79.8 |
| 3806D | 12.9 | 76.6 |
| 3809A | 7.4 | 78.7 |
| 3809B | 7.0 | 73.9 |
| 3809C | 10.2 | 79.2 |
| 3809D | 10.3 | 78.3 |

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